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SOUNDS WE CANNOT HEAR

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CONTENTS

INTRODUCTION

This booklet deals with the achievements of a new, rapidly developing branch of science.

Discovered very early in the 20th century, inaudible sounds immediately drew the attention of research workers in various branches of science and engineering. Several thousand scientific papers have already been published on the properties of inaudible sounds and their practical application.

Supersonic vibrations were first used for practical purposes in France. Especially noteworthy in this connection are the works of Academician Langevin.

Soviet scientists have also played a prominent part in developing the science of inaudible sounds and the methods of their practical application.

Watching the development of science is like reading a thrilling novel. We can all recall reading a book we could not tear ourselves away from. How breathlessly we followed the fate of the hero, how glad we were when he was successful, how sorry when fate was cruel to him! Remember how we yearned to know what awaited him in the future, how we tried to guess which of his plans would be successful and which of them would remain unrealized!

It is the same when you watch the development of science; you are always trying to catch a glimpse of its tomorrow.

In this book we shall tell of various discoveries in the field of inaudible sounds. Some of the applications of inaudible sounds may not justify our expectations in the future; it is quite possible that we shall make mistakes in our explanations of the action of supersonics, and shall have to begin our work anew.... Then we shall recall the words of Karl Marx that "there is no royal road to science, and only those who do not dread the fatiguing climb of its steep paths have a chance of gaining its luminous summits."

If any of our readers should become interested enough in the applications of inaudible sounds to try his hand in this field, he will find the doors wide open before him into the boundless and fascinating world of scientific discovery.

The study of inaudible sounds is at present an unlimited field of activity for investigators of nature, and it opens up immense opportunities for the application of the creative power of man.

Chapter 1

THE WORLD OF SOUNDS

The world we live in is full of sounds. Devoid of sounds, the world would be incomparably poorer. Our conception of a forest is inseparably connected with the singing of the birds, with the rustling of the trees; that of a meadow —with the chirring of the grasshoppers; of the sea—with the roar of the waves and the crash of the breakers; of a city—with the characteristic diversity of sounds known as "city noise," a sort of symphony combining the distant hooting of locomotives, the ding-a-ling of trams, scraps of conversation or music, and the muffled rumble of numerous factories and plants.

Very long ago man learned to find pleasant combinations of sounds, to make up musical melodies. Music is by right considered one of the earliest arts. The magic charm of musical melodies has given rise to many poetic

legends. Our ancestors even used to attribute supernatural properties to music. They held that music could tame wild beasts, move mountains from their seats, hold back floods of water, calm down the raging elements.

Man learned to make musical instruments very early. On Egyptian pictographs we find images of musicians playing flutes and harps. The science of sound, or, as we call it to-day, acoustics, was founded by the ancients. The first experiments in acoustics of which any records have come down to us are those of the Greek philosopher and scientist Pythagoras, who lived twenty-five hundred years ago.

Since that time man has put great efforts into the study of the nature and properties of sound. And gradually, by the end of the 19th century scientists came to believe that they knew practically everything there was to know about sound. It seemed that all that was left in acoustics was to describe already known phenomena, using improved instruments, to refine earlier determined values, but that nothing new would ever be discovered in this field.

But that was a mistake.

Our knowledge of the surrounding world keeps continuously expanding and deepening, "and while yesterday," Lenin teaches us, "the profundity of this knowledge did not go beyond the atom, and today does not go beyond the electron and ether, dialectical materialism insists on the temporary, relative, approximate character of all these milestones in the knowledge of nature gained by the progressing science of man. The electron is as *inexhaustible* as the atom, nature is infinite. . . ."

It turned out that the world of sounds also held secrets, which man had not yet guessed to exist. At the very time scientists were about to yield to the idea that everything in acoustics was already known, a new fascinating chapter was opened in science, the door was thrown wide open

into a hitherto unknown kingdom of nature, the kingdom of inaudible sounds.

This discovery was one of great importance. Having established the properties and peculiarities of inaudible sounds, man began to use them successfully as a means of delving further into the secrets of nature. They became the helpers of man.

FIRST, ABOUT AUDIBLE SOUNDS

It is impossible to understand the properties of supersonic sounds without an acquaintance with ordinary audible sounds. Therefore, we shall tell the reader very briefly what is known about the nature and properties of the ordinary sounds that we can hear.

Let us fix our attention on the sounds that come to us the moment we wake up. There, for instance, goes a factory whistle.

What happened when the whistle bl

The operator opened a valve, and ..pressed air rushed forcibly out into the atmosphere .id expanded, taking up a much greater volume. Unde the impact the molecules of the air also shifted. But molecules cannot travel far. Moving forward abruptly, they mix with the molecules in the air layers in front of them and exert pressure on them. Thus, for a very short moment the number of molecules in the adjacent layers becomes much greater than before. This means that for an instant the pressure in those air layers increases, and the air becomes denser.

The whistle sends forth an intermittent stream of compressed air, and these molecular impacts occur many times each second.

At the instants the air stream is interrupted the shifting of the molecules leads to their momentary deficiency in the layer next to the compressed one. Therefore, next to the high pressure layer there arises a rarefied layer, where the pressure is low. As long as the whistle keeps blowing the compressed and rarefied layers keep running in all directions.

When they fall on the human ear these alternate compressions and rarefactions give rise to the sensation of sound.

Thus, what we call sound is a sequence of rapidly alternating compressions and rarefactions of the air.

The individual particles of air, however, do not move together with the propagated sound. They only oscillate under the impacts of the compressed air, moving to and fro over very small distances.

A similar motion may be observed when a wave runs over the water and the surface becomes uneven: some parts of it rise, forming crests, while others sink, forming troughs, as shown in Fig. 1.

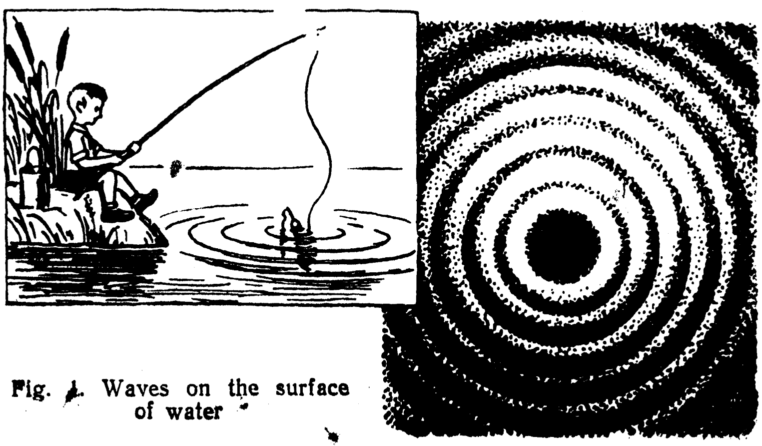


Fig. 1. Waves on the surface of water

A motion like this is called an undulatory or wave motion.

If we observe a float thrown on the surface of water, we shall find that it only oscillates, bobbing up and down, but does not move along the surface together with the running wave.

This shows that the water molecules do not move together with the wave, that they only oscillate on each side of certain mean positions. The undulations, on the other hand, are passed on and on by the molecules, in much the same way as the baton is passed from runner to runner in a relay race.

On the surface of the water each wave crest is followed by a trough; in air through which sound is propagated compressed layers alternate with rarefied ones, and in both cases the separate particles of substance oscillate.

Due to the similarity in the motion of the air particles and water particles, the alternating compressions and rarefactions in the air are called sonic waves.

COMPETING SOUNDS

Sound waves rise and are propagated through the air as a result of the vibration of any body, whether it be a string, a gramophone membrane, the diffuser of a loudspeaker, etc.

Air is not the only conductor of sound waves.

Just before the Battle of Kulikovo in 1380 the Russian Prince Dmitry Donskoi rode out to reconnoitre and, putting his ear to the ground, heard the thud of horses' hoofs: the enemy cavalry was approaching. In this case the sound waves were propagated through the ground.

The rate at which sound waves are propagated through various substances is not the same.

The velocity of sound in air is comparatively small and equals only 1,088 feet per second under ordinary conditions. If we could shout loudly enough for the sound to travel from Moscow to Leningrad (a distance of 373 miles) we should be heard there only half an hour later.

Sound is propagated through water much more quickly: in one second it travels about 4,900 feet. Thus it would take sound about seven minutes to get to Leningrad from Moscow "by water."

The rate of propagation of sound through solids is still greater. For instance, in a steel rod sound travels about 16,400 feet per second and through a steel rail it would cover the distance between Moscow and Leningrad in about two minutes.

In everyday life we distinguish sounds by tone and intensity.

The tone of a sound depends on the frequency with which the body issuing the sound vibrates. The greater the frequency, the greater the number of compressions and rarefactions arising each second in the sound wave, and the higher the tone of the sound.

Frequency is measured in units called cycles per second. A cycle is one complete oscillation or vibration. One thousand cycles make a kilocycle.

It is noteworthy that the rate of propagation of sounds of different tones is usually the same. Therefore, with sounds of higher frequency the adjacent densified and rarefied zones are closer to each other than with sounds of lower frequency.

The distance between two adjacent compressed air zones

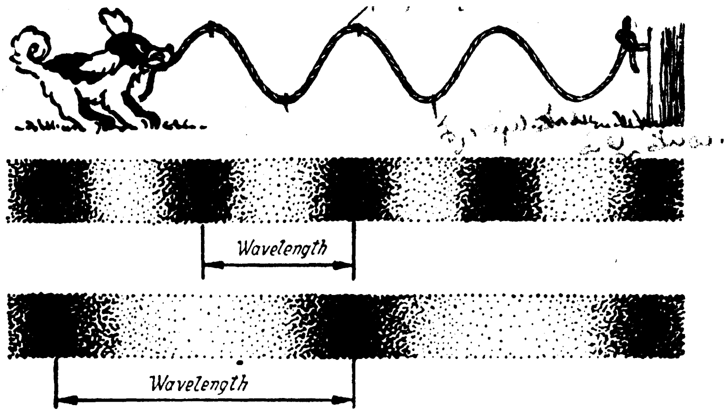


Fig. 2. Distribution of air molecules in two waves of different frequencies

or between two rarefied zones is called the wavelength of the sound. The higher the frequency of the sound, the shorter is its wavelength (Fig. 2).

The human ear is very sensitive to the tone of sound. A person gifted with an ear for music can distinguish between two sounds, one of which has a frequency of 1,000, and the other 1,003 vibrations per second.

However, two sounds of the same tone may have a different effect on our sense of hearing: we say that one of them is more intense or louder than the other. With the same frequency, the intensity of sound depends on the swing or amplitude of the vibrations of the sounding body.

A sounding body vibrating with a wider swing will cause greater changes in the air, and the sound will be more intense; hence, the greater the change in pressure, the higher the intensity of the sound (Fig. 3).

In recent years scientists have engineered sound sources giving tremendous intensities.

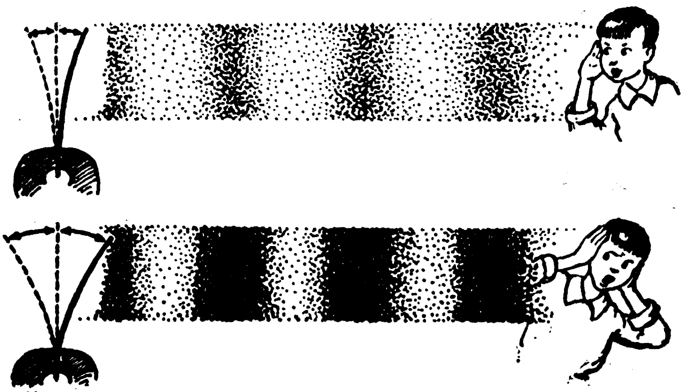


Fig. 3. Dependence of the intensity of sound on the swing of the vibrating body

If we try to transform the energy of sound into heat, we shall see how little energy is radiated by ordinary sources of sound in comparison with modern powerful sound generators. Indeed, in order to heat a glass of water to the boiling point by transforming into heat the energy we expend in talking, we should have to speak continuously for anything between 75 and 2,000 years, depending on the loudness of our voice. If, however, we used the sonic energy radiated by a modern sound source, it would take only about seven minutes.

We usually appraise the intensity of sound by ear, but the intensity of sound cannot be measured in this way, because the sensitivity of the human ear has certain peculiarities. These peculiarities kept us from knowing about the existence of supersonic sounds for a long time, which accounts for the fact that in such an old branch of knowledge as acoustics whole large fields remained unexplored like the "blank spots" on the map.

LIMITS OF AUDIBILITY

The human ear senses sounds of different frequencies differently. It is especially sensitive to sounds within the frequency range between 1,000 and 3,000 vibrations per second. Within this range we can even sense sound waves in which the change of pressure is 1,000 times less than the pressure felt by a human hand when a mosquito settles on it. If the ear were just a little more sensitive it would hear as sound the random increases in the density of the air caused by the chaotic movement of its molecules. And since such increases occur continuously, the world around us would in that case be full of an incessant noise.

The sensitivity of the ear is characterized by the least intensity needed to make a sound heard—this is the threshold of hearing. Naturally, the higher the sensitivity, the lower the threshold of hearing.

As the frequency of the sound decreases, our ability to hear it also decreases and the threshold of hearing correspondingly rises.

In order to be heard, a sound of very low tone, with a frequency of 100 vibrations per second, must be more intense than, for instance, a sound with a frequency of 3,000 vibrations per second.

Sound waves with very slow vibrations, say, from 16 to 20 per second, cannot be sensed at all by our ear.

Such waves are inaudible infrasonic sounds.

The insensibility of the human ear to low-frequency vibrations is very important to man, since it keeps him from hearing the beating of his own heart, which otherwise would sound like an incessant rumble.

The human ear does not hear sounds of very high frequency either. Depending on his age and individuality, man ceases to hear sounds with frequencies above 16,000-20,000 vibrations per second.

These high-frequency sounds, inaudible to the human ear, are called supersonic or ultrasonic sounds.

The physical nature of all sounds, however, is the same, and as we shall see, the division of sound waves into audible and inaudible ones is conventional and is connected merely with the peculiarities of our ear.

Among the waves of frequencies corresponding to audible sounds our ear is incapable of hearing either very weak or very powerful sounds.

When the intensity of the sound becomes high enough man stops hearing the sound and senses the elastic vibrations as pressure or pain. This intensity of sound is called the threshold of feeling.

Experiment shows that sounds of different frequencies begin to cause pain at different intensities; hence, it may be concluded that the threshold of feeling varies with the frequency of the sound. In the region of maximum sensitivity the ear can stand very powerful sounds without feeling any pain.

If the intensity of the weakest sound discerned by the ear is conventionally accepted as unity, the intensity of the most powerful sound of the same frequency which does not cause pain will have to be expressed as a figure consisting of a "1" followed by twelve naughts.

This is explained graphically in Fig. 4. The sound frequencies are plotted along the horizontal axis, and the intensities—along the vertical axis. The lower curve is the

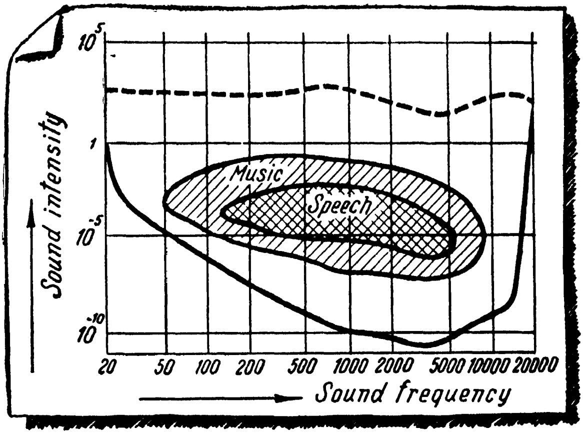


Fig. 4. The audible sound zone

threshold of hearing, and the upper—the threshold of feeling.

The figure shows that the upper and lower curves approach each other both in the high-frequency and low-frequency regions. Thus, a definite zone of frequencies marked off in the figure corresponds to the waves sensed by the human ear as sound. The shaded parts of the figure embrace the waves used in human speech and in music. As we see, these comprise but a very small part of the waves the human ear can sense.

Many of our readers will doubtlessly wonder whether there is any limit beyond which the frequency of sound vibrations cannot be increased.

At the close of last century the remarkable Russian physicist P. N. Lebedev, who was the first to make use of supersonics in research work, noticed that the damping of high-frequency sounds limits their propagation through air. Lebedev estimated that sounds with frequencies of about five million vibrations per second could not practi-

cally be propagated through air: they would be damped right at their source.

Although sound is damped incomparably more slowly in liquid and solid bodies, the frequency of sound cannot be increased indefinitely even in these bodies. Sooner or later we are bound to reach frequencies corresponding to the thermal vibrations of molecules. Those frequencies are the upper boundary of supersonic vibrations. But to reach the upper limit it will be necessary to increase the supersonic frequencies we have attained so far several thousandfold.

Some of the remarkable properties of supersonic sound, such as its ability to accelerate chemical reactions or its capacity for dispersing substances, are due more to its power than to any peculiarities of this kind of sound. When scientists succeeded in creating powerful enough audible sounds, it turned out that the latter have similar effects. Hence, in our times when the practical applications of supersonics are discussed, mention is often made of the possible applications of powerful audible sounds.

Chapter 2

THE FIRST APPLICATIONS OF SUPERSONICS

MANY YEARS AGO

The first practical application of supersonics dates back to the times when our knowledge of sound in general was very scanty. Even the nature of sound was still scarcely known to man, and he had no idea of supersonics.

Observing the world around him, man noticed that dogs reacted to certain sounds which he himself could not hear. This observation led to the first application of supersonics.

From olden times, poachers were cruelly prosecuted by law. They would use a special kind of short whistle, called a "poacher's whistle." This whistle emitted a sound of such high frequency that man could not hear it, but his dog could.

Concealed in the bushes, the poacher could unperturbably call his dog to his side without fear of the warden,

though he might be close by. This is due to the fact that dogs have a different zone of audibility than human beings.

However, poachers pondered no more over the nature of supersonics than primeval man did over the transformation of energy as he drew fire by striking one stone against another.

Supersonics became an object of study a comparatively short time ago.

There was an immense jump in the progress of science in the end of last and the beginning of this century. Those years saw the complexity of atomic structure established, the spontaneous transmutation of some elements into others discovered, various "invisible" rays brought to light, radio invented. All these achievements paved the way for the penetration into one more hitherto unknown sphere of nature—into the world of supersonics.

Supersonic waves were produced in physical laboratories at the end of last century by means of very small tuning forks, no more than several millimetres in length. The frequency of the sound produced was up to 90,000 cycles per second. Special kinds of whistles, "Galton's whistles," were also used for this purpose (Fig. 5). But inaudible sounds did not find practical application at that

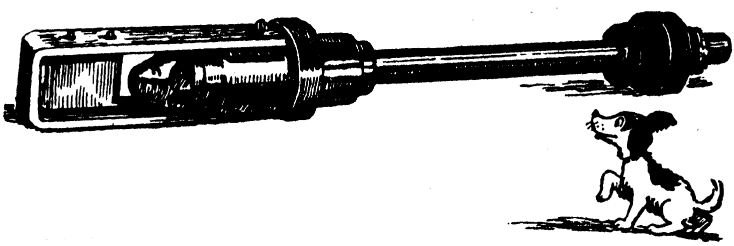


Fig. 5. A modern whistle for producing supersound

time, and that was why this branch of science developed so slowly at first.

The situation changed abruptly, however, when supersonics began to find practical application.

WHEN FRANCE WAS IN DANGER

During the world war of 1914-18 the French Navy suffered great losses from German submarines. The spacious ocean became a literal trap for ships. For a long time scientists strove in vain to find a way of fighting submarines.

One of the scientists who devoted their efforts and knowledge to the cause of the defence of their country was the famous physicist Paul Langevin.

In 1916 he suggested inaudible sounds as a means of detecting submarines. His idea was very simple: a special projector was to send a short supersonic signal in a predetermined direction under the water. If the path was clear, the signal would go on and on and be lost in the ocean. If, however, anything of a density other than that of water happened to be in its way, the sound would be reflected from it and would return to the projector as an echo, showing that there was a foreign object in the sea.

At the same time the distance to the obstruction thus revealed could also be determined.

Suppose the reflected signal returned three seconds after it had been sent. As is known, sound travels through water about 4,900 feet per second; therefore, in three seconds it will have travelled about 14,700 feet. Considering that the sound has to travel forward first and then return, this figure should be divided by two. Hence, in our example the object detected is 7,350 feet, i.e., somewhat under 1 1/2 miles, away.

Our readers, naturally, may ask: why was supersonic sound needed for this device? Could not ordinary audible sounds have served the same purpose?

In 1912, near the coast of North America, the huge British steamer *Titanic* ran into an iceberg and went rapidly to the bottom with most of its crew and passengers. News of the tragic fate of the *Titanic* spread swiftly all over the world. People set to thinking how to avoid such catastrophes in the future.

Could not a sonic echo warn the ship's crew of the impending danger?

However, all attempts to make an instrument of this kind were in vain, owing to one of the fundamental properties of sound.

SOUND AND LIGHT

Imagine yourself in a garden on a summer night by an open window.

The melodious sounds of a piano come pouring out of the room and are slowly lost in the stillness of the night. Note how sharply the bright rectangle of the window is defined on the sand of the garden walk.

If you wish to read anything by the light falling from the window, all you have to do is get into the way of the light rays; and it is enough to take but a step or two aside to find yourself in complete darkness. Light waves travel in straight lines.

Sound behaves otherwise.

Step aside from the window, and that will not keep you from hearing the music. You may even stand next to the window right up close to the wall of the house, and still the sound waves will reach you. Do not think that the sounds you hear come through the wall. If you close the

window you will see that the sounds had been coming through the window.

Why does the light wave travel in a clearly defined beam, while the sonic wave spreads in all directions like the waves formed on the surface of water when a stone is thrown into it?

This difference is due to the difference in wavelengths.

Whether the waves will be propagated in definite directions like light or in all directions at once like sound, depends on the ratio between the dimensions of the source of undulations (projector or aperture in an obstruction) and the wavelength.

If the size of the aperture is smaller than the wavelength or nearly equal to it, the wave will be propagated in all directions at once, as in *a*, Plate I (p. 35).

This is exactly the case with the sounds coming out of the open window. The highest notes of the piano have a wavelength of about three feet, which is close to the dimensions of the window through which the sound emerges into the garden—that is why the sound spreads in all directions.

If the source of wave motion is much larger than the wavelength, the emission will be directional: the wave will be propagated in the form of a beam with more or less defined edges, as in *b*, Plate I.

Light rays have wavelengths of ten-thousandths of a millimetre. Compared with the dimensions of the light wave those of the window are enormous, and that is precisely why the light beam is so sharply defined. The propagation of a wave sent out by a projector is similar to its propagation from an aperture in an obstruction in the path of the wave. Hence, the peculiarities of sonic waves which manifest themselves when the sound comes from the window will be observed also if the window is substituted by a sound projector.

If desired, sound can be directed as well as light; to do this it is necessary either to increase the dimensions of the sound projector or decrease the wavelength of the sound, i.e., increase its frequency. In practice, to get a comparatively non-divergent sound beam supersonic waves must be used.

It was noticed in the very first experiments with supersonic sound that it actually does travel in narrow beams. At present the reason for this is quite clear. Indeed, in water sound with a frequency of 20,000 cycles per second has a wavelength of about three inches; thus, the vibrator, which has a diameter of 20 inches, is about 6.6 times as large as the wavelength. The radiations of such a vibrator are directional, like light rays.

In order to make ordinary audible sounds just as directional it would be necessary to engineer a sound source about 30 feet large. It would be practically impossible to make use of such an apparatus.

That is why the attempts to use audible sounds for the detection of obstacles in the ship's path failed. With ordinary sound sources the echo will return not only from objects in front of the ship, but from objects at its sides and behind it as well.

Now it is clear to us why Langevin employed supersonics for the detection of submarines, this type of sound being easy to send in the form of a narrow beam in the desired direction.

It would seem that the problem of detecting submarines was solved. But this impression was misleading. There were still a great many difficulties to be overcome before this essentially simple idea could be put into practice. Tuning forks and Galton's whistles gave very feeble sounds, which could not be used to detect submarines. And for lack of suitable sources supersonics could not be

used to detect icebergs, although such suggestions were made after the wreck of the *Titanic.*

Practice had set a new problem before science, that of creating a powerful source of supersonic sound.

WONDERFUL CRYSTALS

Many of our readers have seen beautiful specimens of rock crystal or quartz, as it is called in chemistry (Fig. 6).

A small slice cut from such a crystal possesses wonderful properties: if it is compressed, unlike electrical charges appear on the opposite faces of the plate. This phenomenon is called piezoelectric effect, which means the formation of electricity under the action of pressure.

Electrical charges can also be produced by stretching the plate, but they will be opposite to those which appeared upon compression.

If we keep alternately compressing and stretching the plate, unlike charges will keep appearing at its opposite faces. The signs of the charges will keep changing in accordance with the changes in the shape of the plate.

This is not the only wonderful property of the slice of quartz. It was found that if unlike electrical charges are applied to its opposite faces the plate changes shape each time the charges are reversed, growing alternately thicker and thinner.

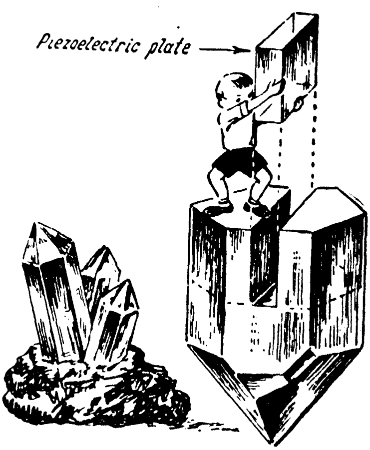


Fig. 6. Quartz and a piezoelectric plate

Now let us place the plate in a gas or liquid. As the plate grows thicker its faces move like pistons in the cylinders of a steam engine and compress the substance in which the plate is submerged. On the other hand, when the plate contracts, the zone of substance adjacent to its surface is rarefied. Thus, the repeated changes in the shape of the plate give rise to alternate compressions and rarefactions in the substance surrounding it. Spreading into space these compressions and rarefactions form a wave; the plate becomes a source of waves, i.e., a projector (Fig. 7).

The shape of the plate can be changed at any frequency by changing the signs of the electrical charges on its faces at the corresponding rate.

At present it is possible to make the plate vibrate thousands of millions of times per second, nor is this the ultimate figure.

It must be remembered that the change in the dimensions of the quartz plate is very small. If a voltage of, say, about 1,000 volts is applied to the plate its thickness will increase or decrease by only two ten-millionths of a centimetre, i.e., by a length that will hold only about 10 to 15 atoms.

But the swing of the plate's vibrations can be increased.

Perform the following experiment: tie a small weight to a string and set it swinging like a pendulum. Note the moment the weight passes through its position of equilibrium by the second hand of a watch, then count off 20 oscillations and find how much time they took. Now, increase the throw by giving the weight a harder push. You will find that exactly the same time is required for 20 oscillations of greater swing. In this experiment the weight

was oscillating freely and we have shown that the frequency-free, or as we say, natural oscillations of a body are independent of the swing, or, which is the same, the amplitude of the oscillations.

But what does the frequency of natural oscillations depend on?

The frequency of natural oscillations of the weight can be changed by merely shortening or lengthening the string it is fastened to. The shorter the string the greater the frequency of oscillations.

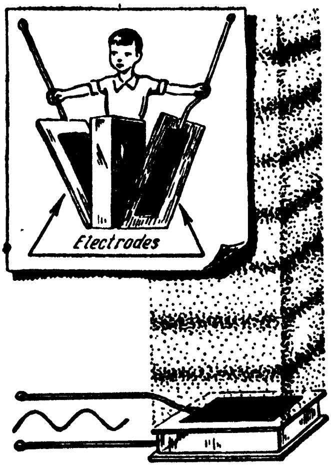


Fig. 7. Piezoelectric projector

Each oscillating body has a characteristic frequency of natural oscillations. Thus, for instance, if a swing is pushed it begins to move to and fro with quite a definite frequency. The throw of its oscillations can be increased by giving it a push. To increase the throw considerably, it is necessary, as we know, to push the swing "in time" with its oscillations, i.e., at a frequency equal to that of its oscillations, if it is left to swing by itself.

The frequency at which the swing has to be pushed to make its throw especially large is called the resonance frequency. All oscillating bodies have a resonance frequency. In those cases where the body is set oscillating at its resonance frequency the swing of its oscillations becomes especially large. There is a case known to history where a small detachment of soldiers marching across a bridge and keeping good step accidentally fell into resonance with the vibrations of the bridge. As a result of

the resonance, the vibrations of the bridge became so great that it fell to pieces.

If the signs of the electrical charges on the faces of the quartz plate are varied at its resonance frequency without changing the voltage applied, the swing of its vibrations will increase and the intensity of the sound emitted by it will grow.

Each plate has its own resonance frequency.

The thinner the plate the higher its resonance frequency. For a plate one millimetre thick it is 2.88 million cycles per second and for a thickness of 0.5 mm.—5.76 million cycles per second. Plates can be made thinner than cigarette paper. The resonance frequency of such a plate is very high, but plates as thin as that are very weak and are not of much use.

And so we see that plates possessing piezoelectric properties are all-important for the production of supersonic sound. For this reason we shall say a few words more about the materials they are made of.

TO NATURE'S AID

Quartz is one of the most common minerals. Ordinary sand consists of tiny particles of quartz. This mineral often occurs in cobblestones which are still used in some places to pave roads. If sand is heated to a very high temperature it fuses into transparent quartz glass which is widely used in chemical laboratories.

It would seem there was no lack of materials for the manufacture of supersonic generators.

Actually, however, this is not so.

Quartz glass does not possess piezoelectric properties and hence cannot be used for the production of supersonic wave projectors.

Piezoelectric properties are peculiar only to crystals of quartz, but large quartz crystals are found very rarely and therefore plates with large surface areas are expensive.

One of the remarkable achievements of science was the recent development of a method of growing large quartz crystals artificially. It was found that quartz crystals can be grown just like crystals of common salt, alum and other water-soluble substances.

At first sight it may seem strange that beautiful rock crystals can be grown from such a stable, insoluble substance as sand or cobblestone. Of course, under ordinary conditions it is impossible.

For this purpose a rod of quartz glass is suspended by means of a fibre in a special receptacle filled with an aqueous solution of certain chemical substances, and below it a tiny quartz crystal is placed (Fig. 8). The receptacle is closed and the temperature within it is raised to 350° C., causing the pressure in the receptacle to rise very high.

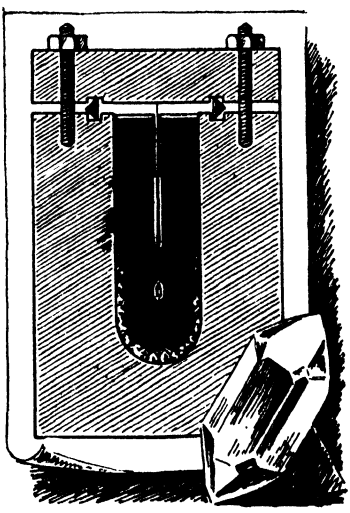


Fig. 8. Receptacle for growing quartz crystals

Under these conditions the quartz glass rod dissolves in the water, and the quartz molecules, having passed into solution, deposit again on the crystal, increasing its dimensions. Part of the dissolved quartz precipitates out on the walls of the receptacle, covering them with a layer of tiny crystals. After about eighteen

Fig. 9. Barium titanate projector

hours the rod has dissolved completely. Then the receptacle is opened and another rod is hung in. If this operation is repeated four or five times a crystal several centimetres large can be grown; such crystals are large enough to be made into piezoelectric projectors.

Further improvement of this method will make it possible to manufacture quartz plates of still greater dimensions. Supersonic generators can be made also of crystals of Rochelle salt, ammonium dihydrophosphate and several other substances.

Besides, Soviet physicists have recently evolved new substances, called titanates, which display an immense piezoelectric effect. Especially prospective for the generation of supersonic sound are ceramic wares of barium titanate. This compound does not naturally possess piezoelectric properties, but the latter can be induced in it, just as magnetism can be induced in steel, which is not naturally magnetic, to make it an artificial magnet.

Since the piezoelectric properties of barium titanate are built up artificially, we can prepare projectors of any shape and make them vibrate in any way desired.

For instance, the barium titanate can be fashioned into a tube which will emit supersonic waves towards its inside. Making the walls of this tube vibrate, we can subject any liquid we pass through it to the action of powerful supersonic waves.

Fig. 9 shows a barium titanate projector in the shape of a cylinder. The conical horn at one end of the cylinder concentrates the supersonic vibrations, making them very in-

tensive. The displacement of the point of this vibrator in operation is about 0.005 millimetre.

At the time Langevin designed his apparatus the artificial production of quartz crystals was unknown. So were the wonderful properties of barium titanate. Scientists and engineers had to content themselves with the small quartz crystals found in nature.

In the attempt to obtain a sharply defined supersonic ray Langevin cemented a whole mosaic of small slices of quartz on a steel plate and covered them with a second steel plate to form the transducer shown in Fig. 10. Now all that was left was to apply unlike electrical charges to the plates and make the signs of these charges keep continuously alternating.

HOW TO MAKE A SUPERSONIC GENERATOR

In our days the signs of the charges on the surfaces of the quartz plates are kept automatically alternating by connecting the plate to an electronic oscillator of the same kind as is used in radio transmission.

A diagram of a simple piezoelectric generator is shown in Fig. 11.

If it is desired to produce supersonic waves of frequencies from 500 thousand to one million cycles per second the coil AC must be about 3 inches in diameter and the copper wire wound on it should be about 80 to 120 mm. (5/64 to 1/8 inch) in diameter. Three

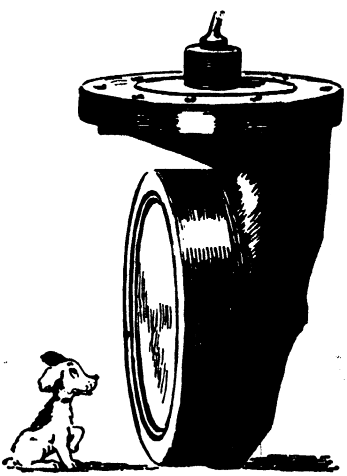


Fig. 10. Langevin's sonic vibrator

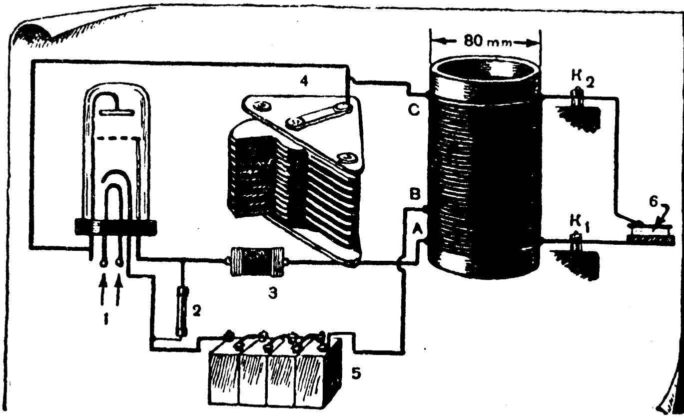


Fig. 11. Diagram of piezoelectric generator:
1—tube; 2—resistance; 3 and 4—condensers; 5—battery; 6—quartz plate

turns are wound between points A and B, and six turns between B and C. The distance between turns is about 5/32″. The quartz plate *6* is placed on a metallic base connected to terminal K_1; the plate is covered with a piece of thin aluminium foil which is held down tight against it by means of a light spring. The latter is connected to terminal K_2. Care must be taken to keep the spring from touching the base.

The high voltage applied to the faces of the plate sometimes causes electrical discharges in the form of sparks running around the edges of the plate. In order to avoid sparking the plate is usually immersed in a liquid of good insulating properties, such as transformer oil.

When the quartz plate vibrates powerfully, the free surface of the oil is raised into a mound, as shown in *c*, Plate I.

If it is desired to produce especially powerful supersonic waves the quartz plate is shaped into a concave mirror. The concave projector converges the sound energy into a point, that is, concentrates it, with the result that the magnitude of power produced in a small space is difficult even to imagine.

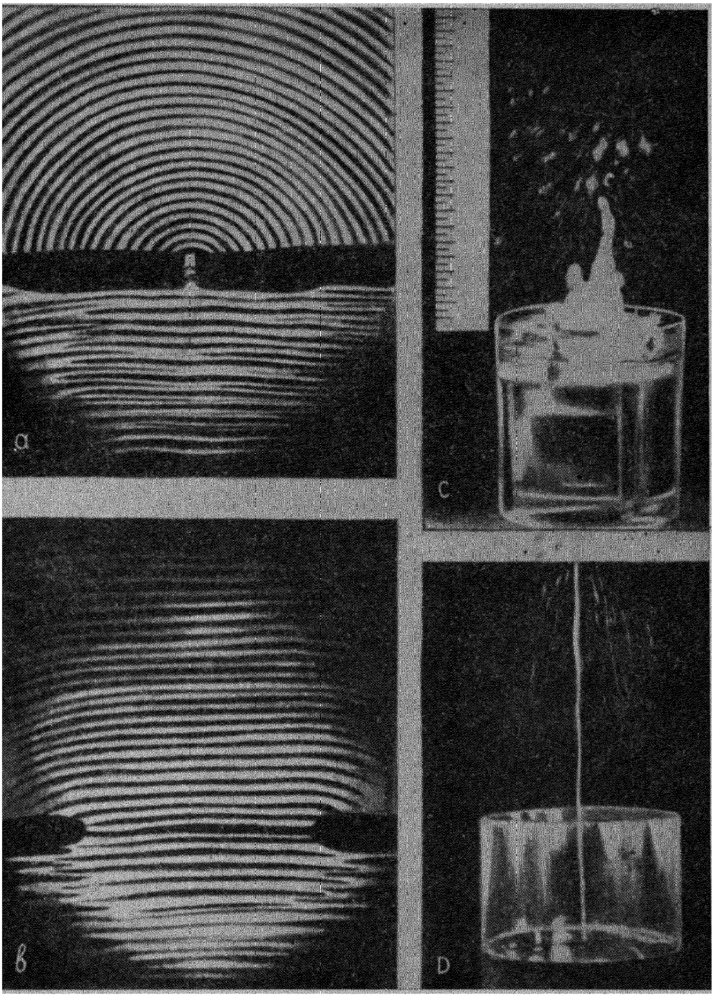


Plate I

a—passage of a wave through an aperture smaller than the wavelength; b—passage of a wave through an aperture larger than the wavelength; c—oil mound forming above a flat vibrating plate; d—oil fountain forming above a concave vibrating plate

If the intensity of a locomotive whistle is taken as unity for the sake of comparison, the intensity of the sound concentrated in the focus of the concave quartz plate will be a figure consisting of a "1" followed by nine naughts, i.e., a thousand million times as great as that of the locomotive whistle.

The pressure variations at this point amount to 120 atm. But the construction of such projectors is very complicated and they are very expensive.

In Langevin's apparatus a little motor running at a constant speed applied a high voltage to the vibrator at definite time intervals, thus making it send short supersonic signals into the ocean.

It now remained only to learn to detect the weak supersonic echoes returning after reflection from some obstacle.

HOW TO "HEAR" INAUDIBLE SOUNDS

To detect inaudible sounds P. N. Lebedev made use of their property of exerting pressure on objects placed in their path. This pressure is very small and is measured with a special sensitive instrument, the supersonic radiometer (Fig. 12).

The design of the supersonic radiometer is as follows: a horizontal rod with a light mica fan on one end is soldered to a very thin wire stretched vertically. The incident supersonic wave exerts pressure on the mica, deflecting it and twisting the wire slightly. The stronger the sound, the greater the pressure, and the more the mica will be deflected.

To determine the deflection of the mica a small mirror is attached to the wire at the point the horizontal rod is soldered to it. If a ray of light is reflected by this mirror, the least deflection of the mica will cause a perceptible

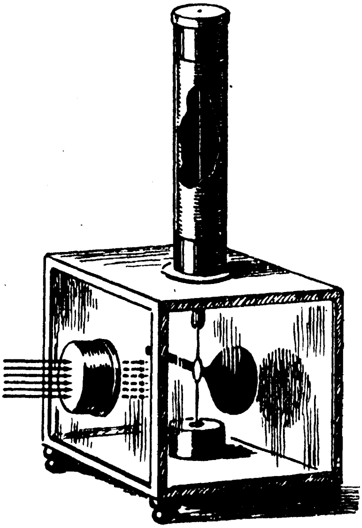


Fig. 12. Radiometer

movement of the reflection. Supersonic sounds can be detected by watching for the movements of this reflection and their intensity can be measured by measuring its deviation.

To protect the radiometer from the influence of various currents which always exist in the air it is placed in a special chamber. The supersonic vibrations pass through a window covered with very thin tissue paper.

The radiometer is still used in laboratory investigations. But for practical purposes—for the detection of submarines—the radiometer was of no use, and Langevin employed for this purpose the same transducer which sent the supersonic beam out on its reconnoitering mission.

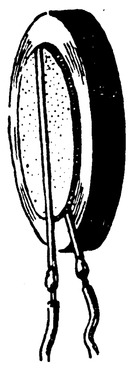


Fig. 13. Piezoelectric supersonic receiver

Having sent the signal the transducer automatically switched over to reception and "listened in" for the returning echo. Falling on the quartz vibrator the supersonic wave gave rise to electrical charges in it which could be detected after amplification. Piezoelectric receivers of this kind are very sensitive (Fig. 13).

As a result of strenuous efforts an apparatus for the detection of submarines, the so-called supersonic hydrophone, was finally created.

Modern supersonic hydrophones are very different from the apparatus designed by Langevin. The sources of supersonic waves in modern hydrophones are usually magnetostrictive instead of piezoelectric oscillators. What are magnetostrictive oscillators?

WHY DO TRANSFORMERS HUM?

Transformers are widely used electrical apparatuses. The simplest transformer consists of two coils of insulated wire on a common iron core.

When an alternating current of comparatively high intensity is flowing through the coils of a transformer, a sound of low tone can often be heard coming from the core.

The humming of the transformer is due to the fact that certain metals and alloys change their dimensions when magnetized.

This property, called magnetostriction, is especially strong in iron, nickel and their alloys. It is exceptionally high in an alloy consisting of 49 per cent iron, 49 per [redacted]alt and two per cent [redacted]m.

If we place a rod of a magnetostrictive material in a coil wound of insulated wire (Fig. 14) and energize it with alternating current, the intensity of which keeps rising

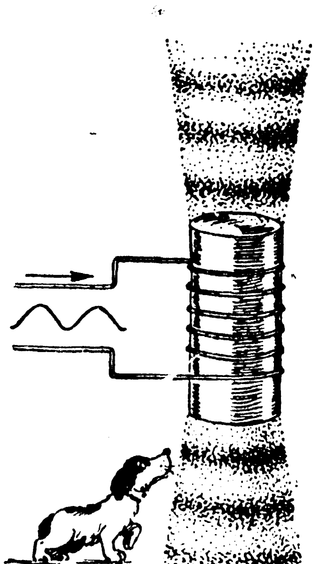


Fig. 14. Magnetostriction rod

and falling, the rod will be alternately magnetized and demagnetized, as a result of which its dimensions will keep changing periodically.

Just as with the quartz plate the changing of the dimensions of the rod gives rise to alternate compressions and rarefactions in the surrounding air, i.e., to a sonic wave. If the frequency of the alternating current is not very high, the sound will be audible, as is the case with the humming transformers. If we increase the frequency of the alternating current supersonic sounds will result. That is how they are produced in magnetostrictive vibrators.

To increase the amplitude of the vibrations, the rod is made to change its dimensions at its resonance frequency, just as in the case of the quartz plate.

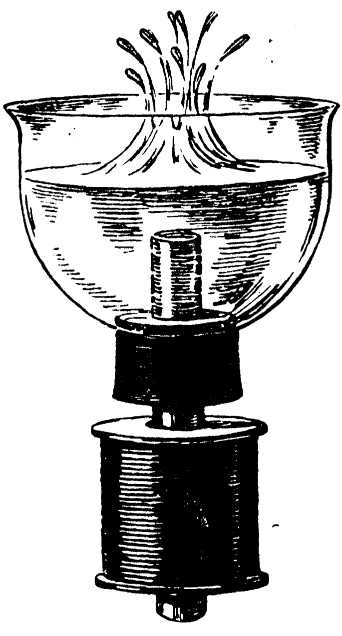


Fig. 15. Magnetostriction rod in a vessel of liquid

The resonance vibration frequency of the rod depends on its length. The shorter the rod, the higher its resonance frequency.

If we pass the end of the rod through the stopper in the bottom of a vessel filled with a liquid we can produce a high-frequency supersonic wave in the latter (Fig. 15). When the magnetostrictive vibrations are very intense the rod gets hot so quickly that it has to be specially cooled. A powerful magnetostrictive vibrator is shown in Fig. 16. It is about one foot seven inches in diameter.

Magnetostrictive and pi-

ezoelectric vibrators supplement one another. Both are sources of sound of frequencies which in the great majority of cases coincide with the resonance frequency of the projector, with that of a metal rod or of a quartz plate respectively.

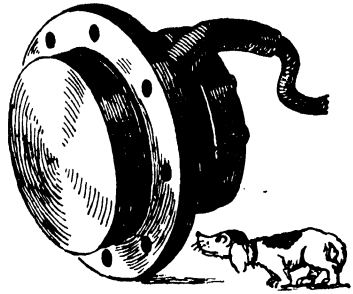


Fig. 16. A powerful magnetostrictive vibrator

It is difficult to make a magnetostrictive vibrator with a very short rod. And since the resonance frequency of long rods is comparatively small, magnetostrictive oscillators are used to produce supersonic sounds of low frequencies approaching those of audible sounds.

On the contrary, piezoelectric vibrators may be used to obtain high-frequency supersonic waves. Besides, piezoelectric and magnetostrictive vibrators differ greatly in design.

That is why both kinds of vibrators are used. In some cases the magnetostrictive vibrator is more suitable, in others—the piezoelectric.

A RELIABLE SCOUT

The hydrophone not only detects submarines, shallows or icebergs, but determines their exact location as well.

The sound used in hydrophonics has an average frequency of between 15,000 and 30,000 vibrations per second.

The duration of a single signal is about 0.1 second.

The moment of emission of the signal is recorded on the screen of a special apparatus called the oscillograph

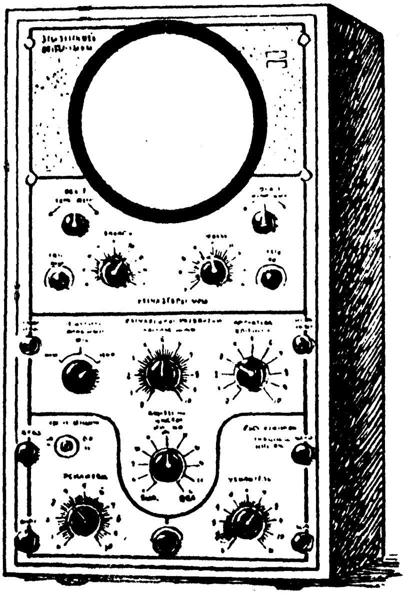


Fig. 17. Oscillograph

(Fig. 17) by the appearance of a sharp tooth-like indentation in the luminescent ray.

As soon as the signal has been sent a special relay (Fig. 18) connects the transducer to a receiving device and the hydrophone waits several seconds for the reflected signal to return.

If an echo returns, a special apparatus first amplifies it, then transforms the inaudible supersonic signals into ordinary sounds which can be heard through a loudspeaker.

At the same time the signals received are transmitted also to the oscillograph and a second tooth-like indentation appears in the ray on the screen.

The longer the time elapsed between the moments of transmission and reception of the signal, the farther away from each other will be the indentations in the ray on the screen of the oscillograph. If the screen is furnished with a transparent scale, the distance to the obstruction which reflected the signal can be determined directly by just glancing at the apparatus.

The transducer is usually enclosed in a special casing and mounted on the ship's bottom. Rotating, the transducer, so to say, "scans the horizon" (Fig. 19).

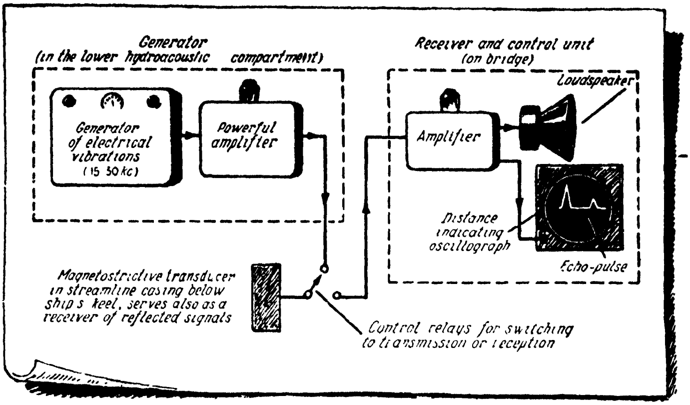


Fig. 18. Schematic diagram of a hydrophone

The distance to the object detected by the hydrophone can be determined by observing the reflected signal by means of the oscillograph.

When, however, the ship is in motion, and the distance between the observer and the detected object is continuously changing, it is sometimes impossible to determine the cause of the echo by its shape. The cause may be a submarine or a reef, or even a large fish.

In coming to a decision on this question it is often helpful to listen to the reflected signal made audible.

An experienced operator can draw many valuable conclusions from the sound of the reflected signal. For instance, by the tone of the sound he can tell whether the obstacle which reflected the signal is in motion or stationary, whether it is approaching or receding.

All of our readers have probably noticed that the tone of a locomotive whistle is higher when the locomotive is approaching than when it is moving away from us.

The explanation of this is very simple. Suppose that at the moment the engineer pulled the whistle the locomotive

was 1,088 feet away from the observer. As we already know, the sound of the whistle is an alternation of compressions and rarefactions. It is they that cause the sensation of sound when they fall on the ear.

The tone of the sound depends on the number of compressions or rarefactions of the air per second.

Suppose the whistle causes 200 compressions per second. If the locomotive and the observer are stationary, the compressions will follow one after another every 200th of a second and will give the observer a sound sensation of a certain tone.

But it is different if the locomotive is approaching the observer. The first compression will take one second to reach the observer, but the next one will reach him sooner, since the locomotive has come a little closer by the time it is emitted. The same will be true of all the subsequent compressions, as a result of which more than 200 compressions will reach the observer every second, i.e., the tone of the sound will be higher.

If the locomotive is receding, the second compression will have to cover a longer path than the first to reach the observer, and the interval of time between them will increase. The ear of the observer will receive less than 200 compressions per second, and the sound will consequently be of a lower tone.

The faster the locomotive is moving, the more perceptible the change in tone at the moment the approaching sound source comes past us and begins to recede.

It is by this change in the tone of the echo that the operator can determine the movement of the object which reflected the signal sent. By observing how the reflected signal first grows louder and then fades away an experienced operator can get an idea of the nature of the obstacle detected in the sea.

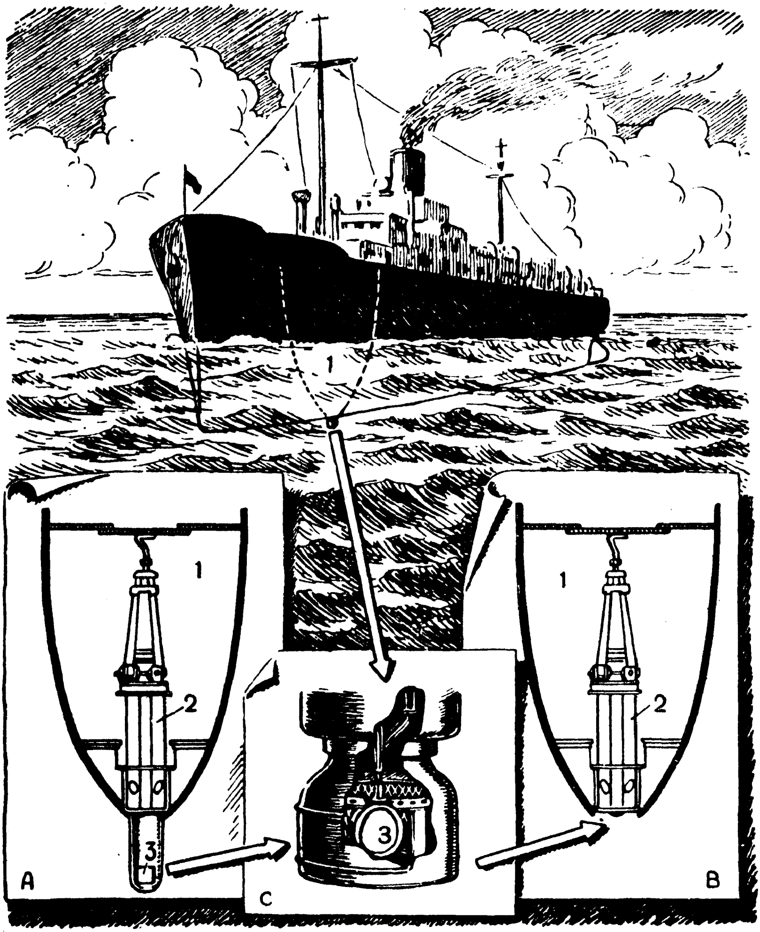


Fig. 19. How the hydrophone is mounted on the ship

The range of the hydrophone varies from several hundred yards to several miles, depending on the conditions existent in the water at the moment of observation. One of the main factors in this connection is the difference in temperature of different water layers, which tends to distort the path of the sound ray. Under such conditions the supersonic signal does not travel in a straight line, but describes a curve bending in the direction of the cooler layers. Another hindrance is the tiny air bubbles liberated by the innumerous microscopic organisms living in sea water. Water layers saturated with air bubbles are very effective sound absorbers, and in some cases may even reflect the signal.

Apparatuses similar to hydrophones may be used for underwater communication, say, between two submerged submarines.

Supersonics may be employed also to transmit signals through the air. True, in this case the range of transmission is greatly limited due to rapid damping of the supersonic waves.

A MECHANICAL WATCHMAN

There is an Arabian story about a magic door which opened only in answer to the words: "Open Sesame!" Supersonics enables us to do even more wonderful things. For instance, we can make garage doors open by themselves only when the owner's car approaches.

For this purpose the car is equipped with a supersonic transducer which emits an inaudible signal as the car approaches the garage. This signal is received by a special

apparatus which turns on a mechanism to open the door. On the approach of any other car not equipped with a supersonic signaller, the doors will remain closed.

If necessary supersonic apparatuses can be used to keep close watch over any room and they have definite advantages in this respect over any other apparatuses designed for the same purpose. Any movement that may arise in the room protected by supersonics will immediately be detected. For this purpose the room is filled with supersonic waves travelling in all directions, which are repeatedly reflected from the various objects in the room. If there is no movement in the room all the echo-signals formed in this way will be of the same frequency. But this condition changes if a moving object appears in the room. The echo produced by reflection from a moving object will differ in frequency from all the other echo-signals. A special highly sensitive echo-signal receiver set up in the same room will react instantly to the appearance of oscillations of a different frequency by switching on an alarm designating that there is some movement in the room. An article in an American magazine tells of a large jewellery shop which was robbed, though equipped with a conventional electric burglar alarm. Instead of using the door or the window where the alarms were installed, the thieves had broken through the brick wall of the shop. After that the shop owner had a supersonic burglar alarm installed and a few months later supersonics helped to catch the thieves who had chosen the ceiling as the entranceway this time. The criminals protested against their arrest on the grounds that they had been caught "unfairly," having taken all measures against conventional alarms, which had not operated as a matter of fact, but never having heard of supersonics.

Now supersonic alarms make it possible to protect large

rooms up to about 10,000 cu. ft. in volume. Supersonic alarms can be employed at some plants to keep men out of danger zones or forbidden zones.

The above supersonic alarms trigger off automatically in case of fire. The rising column of hot air coming from the flame is an excellent reflector of supersonic waves and gives echo-signals whose frequency differs from that of the basic signals. Several cases of fires being averted at American enterprises equipped with supersonic alarm systems have already been registered.

What we have mentioned here does not by any means exhaust the possibilities which came up before mankind when the properties of supersonic sound became known. The most daring dreams become realities as a result of the use of inaudible sounds and their peculiarities.

THE SUPERSONIC ECHO SOUNDER

In our days automatic supersonic echo sounder is used not only to measure the depth of the ocean and investigate the relief of its bottom, but to detect various objects there as well.

This device is similar to the hydrophone.

A supersonic magnetostrictive vibrator *4* (Fig. 20), mounted on the ship's body, emits short signals at definite time intervals, usually once a second; the signal is recorded automatically on special tape. All the operations in the echo sounder are automatic. When the supersonic echo returns after reflection from the bottom, it is received by the magnetostrictive receiver *3*, passes through an amplifier *2* and is registered on the tape. Thus, two lines appear on the moving tape: one of them, *O*, corresponds to the emission of the signals, i.e., to the ship's bottom, and the other, *D*, to the return of the echo, i.e., to the sea

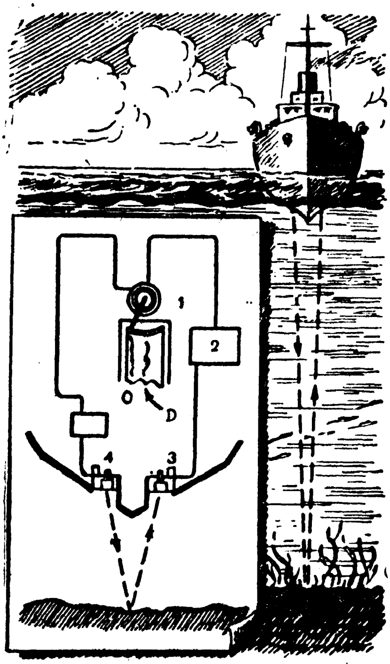


Fig. 20. Diagram showing how the echo sounder works

bottom. The greater the distance between these two lines, the greater the depth of the ocean at the point measured. If a special scale is applied to the tape the depth of the ocean can be measured in feet. Such depth records are called bathograms.

Modern sounding apparatus are designed so that a neon light flashes on at a point on a special scale corresponding to the depth of the ocean under the ship. By watching this scale the navigator can always know the depth of the ocean at the point the ship is passing. The echo sounder not only gives warning of reefs and shallows, but makes it possible to determine the bearings of the ship as well.Very detailed maps of the ocean floor have been compiled. By using such a map and a bathogram, the ship's bearings can be determined even when it is impossible for some reason or other to do so by other means.

An echo sounder helped to find one of the deepest spots in the ocean, a depth in the Pacific Ocean amounting to 35,630 feet.

The advantage of supersonic echo sounder is that it can be used in almost any weather without slowing down

the ship's headway and for measuring both very great and very small depths.

The accuracy with which the echo sounder determines the relief of the ocean's bottom is so high that it may be used to find sunken ships. Fig. 21 shows the silhouette of the *Lusitania* at a depth of 100 metres, recorded by means of an echo sounder.

The use of this device in fishing is of great economic importance.

The swimming bladders of fish are filled with air and therefore reflect supersonic signals very well, making it possible to detect schools of fish by means of a sounding machine. Fig. 22 shows the tape of an echo sounder with the record of a detected school of herring on it. The upper boundary *1* corresponds to the surface of the sea. The lower zigzag line *2* corresponds to the sea bottom. The line *3* recorded by the sounding device between the surface and the bottom of the sea was caused by reflection

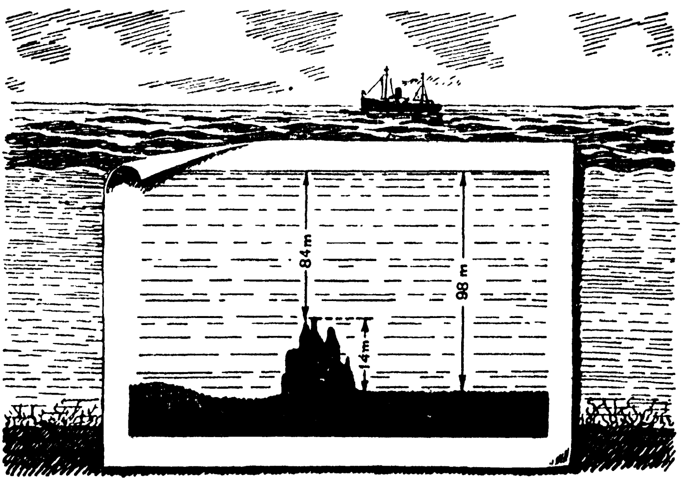


Fig. 21. Silhouette of the *Lusitania*

of the supersonic signals from the school of herring. Records of this kind make it possible to estimate not only the location of the school but its size as well.

The use of supersonics in searching for schools of fish greatly increases catches and shortens the duration of fishing expeditions.

In the near future echo sounders will undoubtedly find even wider use in fishing.

In hydrophones and sounding devices supersonic sounds are detected by their action on a special receiver.

At present several methods have been developed to render supersonic sounds visible as well, offering an interesting opportunity of watching the course of the supersonic beam.

SUPERSONIC WAVES BECOME VISIBLE

On hot summer days streams of air heated by the surface of the ground can be seen rising above the road. These streams become visible due to the air expanding when heated, decreasing its density and changing its optical properties, viz., lowering its coefficient of refraction. For a similar reason streams of compressed air, the density of which is greater than that of the surrounding air, would also be visible.

The same phenomenon can be observed in liquids. Pour some warm water into a glass, put a book behind it and carefully add some cold, and, consequently, denser water. Streams with different optical properties immediately appear and the letters on the page observed through the glass of water will seem to fluctuate and become diffused.

If the glass is illuminated by a candle so that its shadow falls on a clean sheet of paper, these streams will be clearly visible on the shadow.

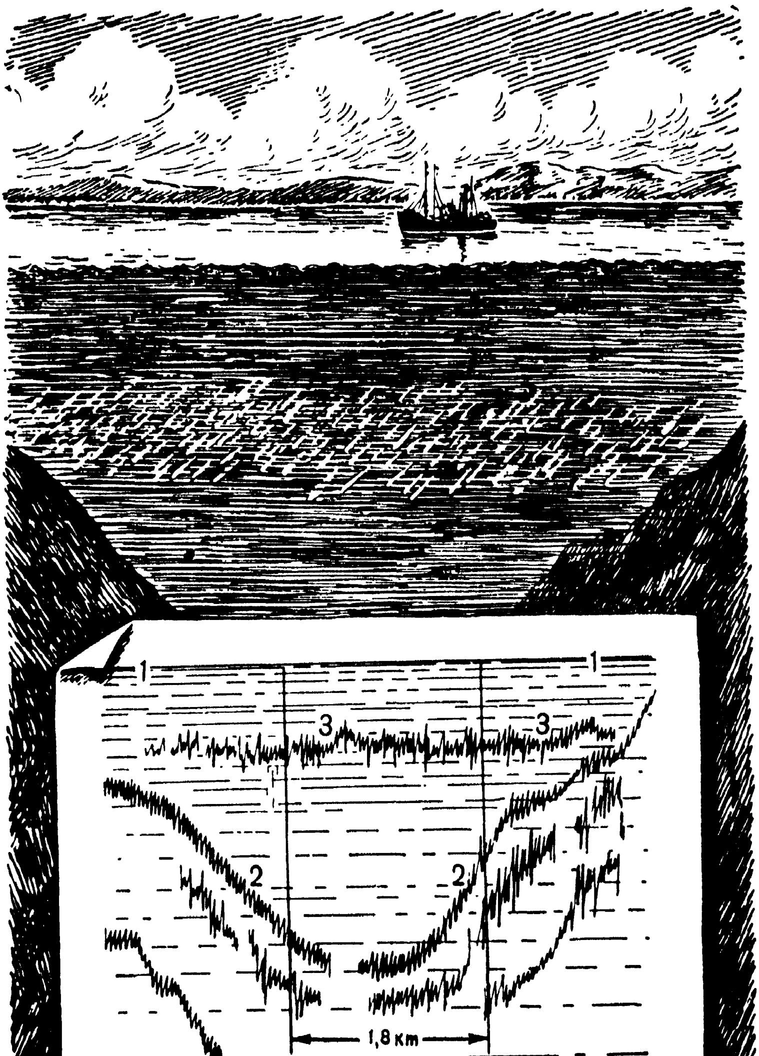


Fig. 22. A school of herring registered
by a sounding apparatus

When a sound wave is propagated alternate compressions and rarefactions, i.e., changes analogical to those mentioned in the above experiment, occur in the air. Hence, a shadow image of the sound wave can be obtained in the same way as the image of the water streams with different temperatures. It should be remembered, however, that in a passing sonic wave the compressions and rarefactions alternate very rapidly. If we wish to get an image of the wave we must illuminate it for a very short period of time, before the pressure distribution has had a chance to change appreciably. In practice, to obtain an image of sound waves intermittent light is used which flashes on and off at the same frequency as the quartz plate vibrates. The light flashes coincide with the same position of the vibrating plate each time, making the image of the sonic wave on the screen "rigid" and clear-cut.

If the screen is replaced by a photographic plate the wave can be photographed.

All this made it possible for the Soviet scientists S. N. Rzhevkin and S. I. Krechmer to employ supersonics in a model study of the acoustic properties of various structures: concert halls, lecture rooms, etc.

Fig. 23 shows the propagation of a wave with a column in its path. The "acoustic shadow," a dark zone behind the column, can readily be seen. In the acoustic shadow zone the sound

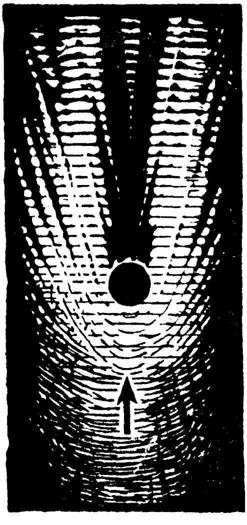


Fig. 23. Acoustic shadow of a column

will be weaker. This method can be used to solve various kinds of problems in architectural acoustics.

When studying the acoustic properties of a projected concert hall or theatre on a small model, ordinary sonic waves cannot be employed. The behaviour of the wave as it goes through an aperture in an obstruction or passes an obstacle in its path, as we know now, depends on the ratio between its wavelength and the dimensions of the aperture or obstacle. For this reason, in modelling it is necessary to reduce the wavelength of the sound in proportion to the decrease in the dimensions of the structure. If we use supersonics, i.e., very short wavelengths, the models can also be made of small dimensions.

But how to obtain an intermittent illumination of a high enough frequency to correspond to the supersonic waves?

If the brightness of the light does not have to change too rapidly, an ordinary electric lamp can be employed, by varying the voltage of the current feeding it. If the brightness must vary very rapidly, this method is useless, since the hot filament of the lamp will not have time enough to cool down and the brightness of the light will remain constant.

The voltage of the electric current usually employed in lighting falls to zero 100 times a second, without any changes in brightness being noticed. Even this relatively long interval of time is not enough for the filament of the lamp to cool down.

The necessity of rapidly varying or modulating, as it is called, the intensity of light arises often in practice: in sound recording, in television, in investigating the operation of rapidly moving machine parts, etc.

This problem can also be solved by applying supersonics.

To vary the brightness of light rapidly use can be made of the changes caused in the optical properties of substance

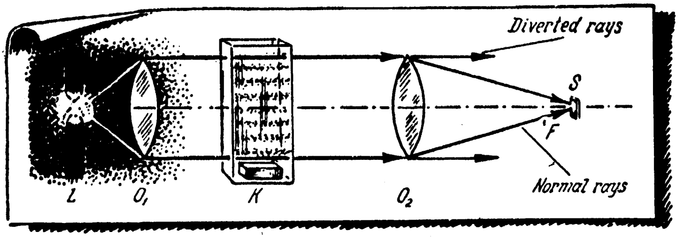


Fig. 24. Diagram of supersonic modulation of light

by the passage of sound through it. Fig. 24 shows one of the possible arrangements for the supersonic modulation of light. The lens O_1 gathers the light rays diverging from the light source L into a beam of parallel rays, which, after passing through the glass bath K, is converged by the lens O_2 to the focus F. The further progress of the rays is stopped by the screen S. The bath K contains a transparent liquid with a piezoelectric plate submerged in it. If the plate is set vibrating and emitting supersonic waves into the liquid, the latter will become optically non-homogeneous. This will change the paths of the light rays. A certain part of the rays will fail to converge at F and will therefore not be stopped by the screen. The higher the intensity of the sound, the more rays will miss the screen. In its turn, the intensity of the sound depends on the voltage applied to the piezoelectric projector. If the voltage is varied the intensity of the supersonic vibrations will vary with it, and thus modulate the brightness of the illumination beyond the screen.

Not long ago supersonic light modulation was used in signalling devices for sending secret messages. The changes in light intensity caused by supersonic vibrations were transmitted to an observer armed with a telescope. In the telescope the light rays fell on a photoelectric cell which converted them into electric current. The greater the

intensity of the light, the stronger the current. The message was deciphered by the changes in current. In the daytime such signals could be transmitted almost two miles and at night, about three.

With the help of supersonics very powerful sources of modulated light can be obtained with intensities varying at almost any frequency.

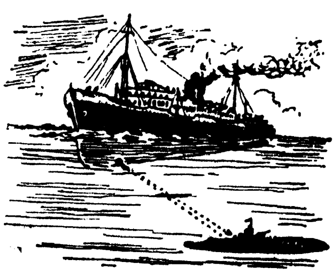
If such a ray is run over a screen, scanning it line by line, it may be employed to obtain a television image.

The visible image of the light wave makes it possible to draw conclusions as to the absorption of sound by various materials on the basis of the intensity of waves reflected from and transmitted through obstacles.

Experience has shown that the study of various undulatory processes by the use of models permits the reproduction of a detailed picture of the phenomena observed therein.

If we photograph the picture observed we can clearly trace on the snapshot the wave coming from the source, its meeting with the obstacle, the appearance of the reflected wave, the interaction of the latter with the incident wave, etc. All this is difficult, and sometimes altogether impossible, to observe without the help of inaudible sounds.

The peculiarities of supersonic sound mentioned above are of great importance at school. In this way the pupils can be shown the laws of propagation of sonic and supersonic waves, rendering instruction more graphical and convincing.



CHAPTER 3

SUPERSONICS AND LIVE CREATURES

THE RIDDLE OF BATS

Without suspecting it we are constantly encountering inaudible sounds in everyday life.

Having built sensitive supersonic receivers, scientists found that even familiar sounds, such as, for instance, the ringing of a telephone, the ticking of a clock, the roar of an aeroplane, contain inaudible sounds along with the usual audible ones.

Placing special apparatuses in the woods, investigators found that the apparently sleeping forest, submerged in the stillness of night, was actually full of the squeaks and cries of its numerous inhabitants.

Some domestic animals can readily sense or "hear" supersonic sounds.

Cats can hear supersonic sounds of not very high tone. In various languages cats are called by uttering sounds similar to the English "puss, puss." It has been found that this combination of sounds contains supersonic sounds as well as the vibrations sensed by the ear.

Some species of birds are sensitive to supersonic sounds. There has even been a suggestion to use supersonic apparatuses to frighten away the gulls contaminating fresh water reservoirs.

The part played by supersonics in the life of bats has been studied in especially great detail. Bats have very poor eyesight, but this does not keep them from orientating themselves excellently and never missing when they attack the small insects they feed on.

It might have been assumed that in hunting for food bats are guided by their excellent sense of hearing and not by eyesight; but then it remained quite a riddle how bats managed to detect in the dark even such small obstacles in their path as thin tree twigs or telegraph wires.

About two hundred years ago the Italian scientist Spallanzani first studied these peculiarities of bats in detail. In the attempt to find out which of the bat's sense organs helps it to orientate itself in flying, he alternately deprived it of the senses of seeing, taste, smell and touch. He found that a blind bat could fly just as well as one with eyes. Depriving the bat of the senses of smell, taste and touch did not change anything either. It remained to assume that the bat orientated itself by ear. Indeed, as soon as its ears were plugged it began to dash about helplessly from side to side, bumping into various objects.

These experiments showed clearly that bats found their way in flight by ear. But it is impossible to orientate oneself correctly with the help of audible sounds! The riddle of bats has been solved only in our days!

When it was found that inaudible sounds travel in narrow beams, making it possible to detect objects in their paths, scientists began to wonder whether it was not supersonics that substituted eyesight in bats.

By using special piezoelectric receivers it was established that during its flight the bat emits short supersonic signals at definite time intervals. These signals have even been recorded on a film. Clever experiments have led scientists to the firm belief that the bat hears the sounds it emits.

The ratio between the wavelength and the dimensions of the bat's mouth when open, the mouth being the projector of the sound, makes the signal sent by the bat directional, like the signals of a hydrophone.

When the bat is at rest, it emits 5 to 10 signals per second. In flight, however, it cries out more often, emitting an average of 30 signals per second.

After sending its supersonic signal the bat listens carefully to catch the echo of the signal with its immense ears. As soon as the echo comes back it sends the next signal. The closer the obstacle, the more often the bat cries out. At a distance of sixty-five feet it emits about eight signals per second, increasing this number to sixty as it comes within three feet of the obstacle.

Careful observation of the behaviour of bats has brought scientists to the conviction that these animals also orientate themselves by the way the signals become more intense as they come closer to the obstacle.

It has recently been found that some species of bats make use of both methods of orientation simultaneously.

Supersonic sound damps very quickly in air, and this greatly limits the bats' capacity for orientation, narrowing their "horizon." They are probably incapable of detecting objects more than sixty-five feet away.

By reproducing the signals usually sent by bats with special projectors, investigators have found that moths and other insects on which bats feed also sense, or "hear," these sounds. When, for instance, a supersonic beam was directed at some moths, their behaviour changed abruptly: a moth which had been flying along tranquilly, darted aside, as if fleeing, another unexpectedly folded its wings and fell to the ground, "playing dead."

Doubtlessly this sensitivity to supersonic sound is a protective adaptation of these insects.

Various studies carried out with a view to elucidating the role of supersonics in live nature suggested a wonderful invention to man, in which he attempted to make use of what he had found in nature.

ALONG THE PATH POINTED OUT BY NATURE

One of the worst misfortunes that can befall a man is loss of eyesight. In numerous legends and tales man has expressed his dream of learning to conquer blindness. In *Ashik-Kerib*, a story by Lermontov, the powerful magician gives Ashik a lump of earth and says: "If they fail to believe the truth of thy words, tell them to bring thee a blind woman who hath been so for seven years; smear her eyes with this and she will begin to see again." This was to have been a miracle which would prove the omnipotence of the magician and the truth of Ashik's words.

Modern medicine has made great progress in combating blindness. In our days returned eyesight is by no means a rarity. Soviet physicians under V. P. Filatov have carried out many thousands of such operations. But sometimes physicians are powerless in this respect.

The fact that the bat can find its way through space very well with the aid of supersonics led scientists to the idea of making it possible for a blind man also to detect obstacles in his way when walking along the streets of a city without having to resort to the aid of his fellow creatures.

In one of the apparatuses designed to enable a person to find his way with the help of supersonics the projector sends about ten short signals, inaudible to the human ear, each second. A few instants after sending the signal the apparatus automatically switches over to reception and listens in for the return echo. A special device converts this echo into audible sound, which can be heard by the blind man.

By the intensity of the echo the man can determine the distance to the object it was reflected from: the greater the distance, the weaker the echo.

In another apparatus the time interval between the emission of the signal and the switching on of the receiver can be changed as desired by means of a special regulator. If the interval is increased the echo will arrive before the receiver is turned on and will not be heard. Gradually changing the moment of switching on the receiver, the latter can be made to switch on, in imitation of the bat, exactly at the moment the echo arrives. In this case the distance to the obstacle the signal was reflected from can be estimated by the position of the regulator knob: the later the echo returns, the farther off is the obstacle.

Experimental specimens of these apparatuses permitted their operators to distinguish objects at a distance of several yards. It should be noted that supersonic apparatuses have a very "sharp eyesight": they can even discern a string stretched out about a foot away.

These experiments are but a first attempt to approach

a still distant goal. But we can say for sure that the daring thought, persistence and clearness of purpose of scientists will overcome all difficulties, and that in the end such an apparatus will be created.

Of course, vain hopes should not be engendered in this connection. Even when such an apparatus is created, it will not be of much help in finding one's way along a crowded city street with its endless stream of hurrying pedestrians, and with its automobiles, trolleybuses and trams shooting by.

The apparatus would register so many echo-signals each moment that it would be practically impossible to understand them. However, at home or in rural districts, where the traffic is not so great, the supersonic ranger can be of great help to a man deprived of the sense of seeing.

ACTION OF SUPERSONICS ON SIMPLEST LIVING CREATURES

The very first experiments with powerful supersonic radiations showed that the simplest living creatures are quickly destroyed by supersonic rays.

The Soviet scientists G. B. Dolivo-Dobrovolsky and S. I. Kuznetsov discovered that the unicellular organisms and infusoria which inhabit almost all bodies of water perish very quickly under the action of supersonic waves.

A microscopic investigation of water treated with supersonic waves did not reveal a single live infusorian.

If a special apparatus taking 1,200 photographs per second is connected to the microscope, all the stages of destruction of the microorganisms by supersonics can be photographed.

Experiment showed that the time required to rupture a single cell is less than 1/1,200 of a second: in one photograph the cell could be seen yet uninjured; in the next it was already completely demolished.

The reason for the death of the simplest organisms under the influence of supersonics has not been established exactly as yet, but certain assumptions may be made.

We know that supersonic waves consist of alternate compressions and rarefactions. When a powerful supersonic wave is propagated through water, the rarefactions may be so great that the water cannot withstand the tensions which arise and is torn asunder. In the places where the ruptures occur tiny bubbles appear, filled with the vapours of the liquid and the gases dissolved in it.

The occurrence of such microscopic ruptures is called cavitation. The greater the power of the sound, the higher the intensity of the cavitation incurred. After making its appearance the bubble lasts for a very short time and then collapses and disappears.

The collapse of the cavitation bubbles gives rise to immense pressures amounting to thousands of atmospheres, which undoubtedly plays a great part in the biological effect of supersonics.

The importance of cavitation can be seen from the following example: in some cases it was enough to prevent the occurrence of cavitation bubbles by raising the external pressure for the supersonic waves to lose their deadly effect on the cells.

The destruction of various disease bacteria by the action of powerful supersonic waves is of great interest. Bacteria excreted from a diseased organism and placed in a vessel with a substratum perish rapidly when treated with supersonic waves; even such stable bacteria as tubercle ba-

cilli perish. Diphtheria bacteria are completely destroyed in a few minutes.

A study of preparations of various bacteria after supersonic treatment under the electron microscope which gives magnifications of tens of thousands of times, made it possible to reveal the exact changes caused in them by supersonics.

Figs. *a* and *b*, Plate II, are photographs of tubercle bacilli. In *a* we see the intact tubercle bacilli magnified 30,100 times. In *b* the destruction of the tubercle bacilli under the action of supersonic vibrations can be seen. It should be noted that even prolonged treatment did not lead to complete destruction of all the tubercle bacilli.

Figs. *g* and *h*, Plate II, are photographs of one of the species of bacteria magnified 10,850×. Figure *g* shows the microorganism before treatment, and figure *h*, after 10 minutes' treatment with supersonic waves of a frequency of 700,000 vibrations per second. It can be seen that under the action of the supersonic rays the bacteria have lost their clear-cut outline and have acquired a sort of "atmosphere" with irregular and diffuse boundaries.

Various kinds of viruses are also subject to the destructive action of supersonic waves.

Figs. *c* and *d*, Plate II, are photographs of the virus of feline pneumonia, magnified 13,570× before and after supersonic treatment.

After treatment the virus ceases to cause the disease.

Figs. *e* and *f*, Plate II, show the changes that take place in one of man's most dangerous enemies—the grippe virus—under the action of supersonic vibrations. Although the changes in this case are not so clearly defined, an hour's treatment with supersonic waves decreases the activity of the virus a thousandfold.

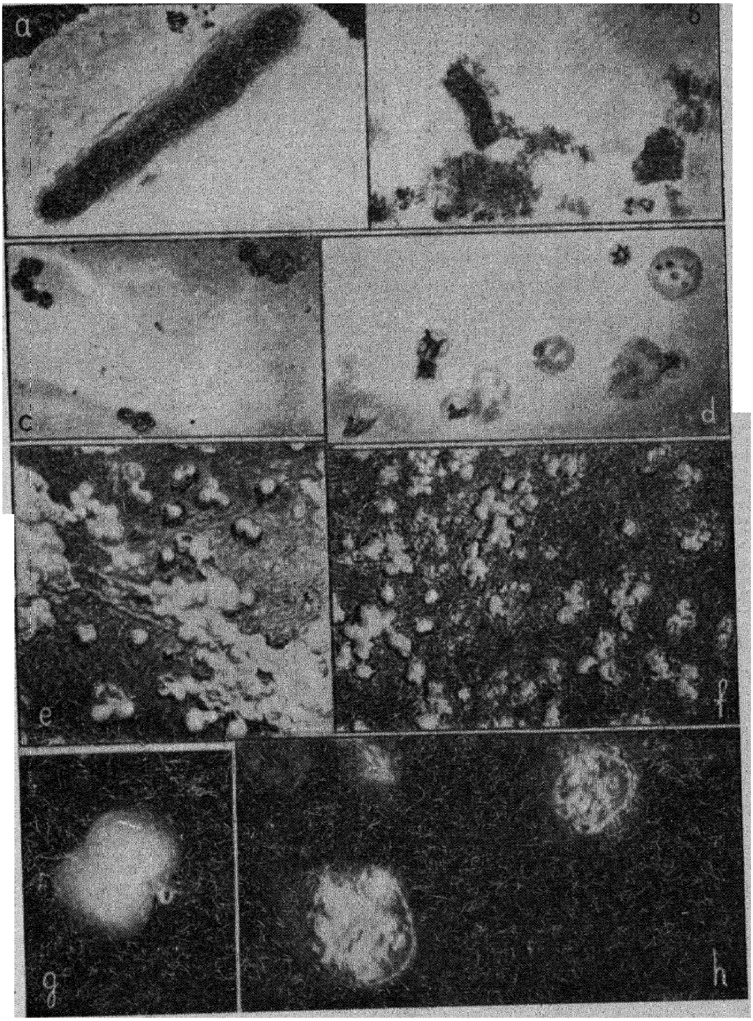


Plate II

a, **b**—effect of supersonics on tubercle bacilli; **c**, **d**—effect of supersonics on the feline pneumonia virus; **e**, **f**—effect of supersonics on the gripple virus; **g**, **h**—effect of supersonics on bacteria

V. A. Kuteishchikov, a Soviet scientist, has succeeded in weakening the virus of spotted fever by subjecting it to the action of supersonic waves for 30 seconds.

The capacity of supersonics for killing microorganisms makes it possible to use it to sterilize water, milk and various other foodstuffs.

Very interesting attempts have been made to employ supersonics for the extraction of various important biological substances from microorganisms: toxins, enzymes, etc. Various serums have recently been successfully prepared with the aid of supersonics.

By treating whooping cough bacteria with supersonics scientists have isolated the poison they deposit, known as endotoxin. If this endotoxin is kept in the cold for some time, it loses its toxic properties, becomes harmless, but retains its capacity of imparting immunity to animals, i.e., making them not subject to the disease. The advantage of the supersonic method of producing toxins, enzymes and other biological substances is that during the short time it takes to destroy the cell its contents do not get a chance to undergo chemical change, and they pass into the surrounding medium without alteration.

There is no doubt that in the near future supersonics will be widely used for the production of various biological preparations.

WHAT HAPPENED TO THE FISH?

Here is a vessel of water with little fishes darting gaily about in it.

But what has happened?

Why have the movements of the fishes suddenly become erratic? Why do they float helplessly on the surface underside up, trying in vain to right themselves?

This is due to the supersonic vibrations which have appeared in the water. Switch off the supersonic source and the fishes will resume their gay darting around, as if nothing had happened to them. But if the power of the sound is increased, the fishes will be killed.

The effect of supersonics on tadpoles is much the same. True, unlike the fishes, which when subjected to supersonic vibrations still try to right themselves, the tadpoles completely lose their ability to move.

Alongside their property of destroying live organisms, supersonics may in some cases stimulate vital processes. For instance, if the seeds of sweet peas are treated with supersonic waves they begin to germinate violently. But experiments of this kind should be carried out very carefully. Intense supersonic waves act very severely on the organism.

Men operating powerful sirens noticed that whenever their hand got into the path of the sound ray their fingers became unbearably hot in a few seconds. This is probably due to the fact that the heat generated by the action of sound arises in the very tissues of the organism, instead of being conducted to them as is the case when warming in the usual way.

Once when the operator of a powerful siren accidentally got into the way of the sonic wave for a few moments, he immediately began to feel nauseous and to lose his balance, in spite of the fact that he had special sound absorbers over his ears.

Supersonic waves of smaller power behave differently. Their action on the human organism may be beneficial. In this respect supersonics may be compared with sunlight, which causes sunburn when used immoderately, but if applied correctly, restores people to health.

In recent years scientists have succeeded in developing

several methods of treating various disorders by means of supersonics. In one of these methods the supersonic source is pressed firmly to the part of the human body which is to be treated with high-frequency vibrations. In another the projector is passed to and fro over the surface of the skin in the place to be irradiated. The skin is first smeared with paraffin oil to make it conduct the sound vibrations better.

Fig. 25. Instrument for determining the power of supersonic vibrations

One of the main difficulties connected with the use of supersonic vibrations in medicine is the lack of well-developed methods of dosing them. Fig. 25 shows one of the instruments for determining the intensity of a supersonic beam.

Scientists are also persistently investigating the processes that take place in live organisms under the influence of supersonics.

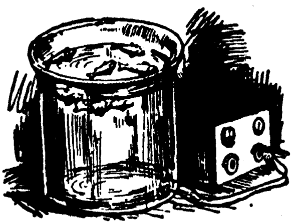
There is no doubt that besides cavitation, which ruptures the simplest organisms, the chemical action of supersonics on the complex organic substances present in live cells must also be taken into account.

Under the action of powerful supersonic vibrations large protein molecules break up, forming particles of smaller size.

Supersonics is also capable of changing the chemical and biochemical properties of molecules less complex in structure and more stable in nature than protein molecules.

There is a chemical compound called benzopyrene which possesses the property of giving rise to malignant tumours in animals. After supersonic treatment benzopyrene loses this property.

Investigations of the chemical effects of supersonics will help to promote the further use of inaudible sounds in biology and medicine.



Chapter 4

SOUND AND CHEMISTRY

THE FIRST STEPS

Just as an explorer who setting foot on a newly discovered land does not know at times whither to direct his steps, so researchers in a new branch of science move forward at first diffidently, "by touch."

It was the same with the investigations in the field of inaudible sounds.

As more and more new properties of supersonic sound were discovered, the nature of the phenomena observed became better and better known, and scientific researches became more and more clear of purpose.

This was a thrilling voyage, in which man kept continually coming up against hitherto unknown phenomena, and no wonder, therefore, that the very first steps taken

by the research workers led to discoveries which drew the attention of scientists throughout the world to the wonderful properties of inaudible sounds.

A point of especially great interest was the ability of supersonics to cause chemical changes. The number of chemical changes brought about by supersonics was found to be so great that there was even a suggestion to unite them into a special branch of chemistry, called sonochemistry, just as the chemical phenomena caused by light come under the heading of photochemistry. Perhaps, in the future such a branch of chemistry will actually be recognized.

Potassium iodide is a colourless substance, difficult to distinguish by appearance from common table salt.

An aqueous solution of potassium iodide is colourless and has a bitter-salty taste. If it is treated with a powerful supersound the solution turns slightly yellow.

What has occurred?

Under the action of the supersonics the potassium iodide molecule, which consists of one atom of iodine and one of potassium, decomposes, liberating iodine, which colours the solution.

A chemist would say that oxidation had taken place, resulting in the liberation of iodine. Indeed, the same is observed if hydrogen peroxide or any other substance capable of causing oxidation is added to the potassium iodide solution.

But the oxidizing action of supersonics is not limited to the decomposition of potassium iodide.

If solutions of organic dyes, such as, for instance, Congo red or methyl violet, are subjected to supersonic treatment, they are discoloured just as if some powerful chemical oxidizer had been added to them.

A study of the chemical changes that take place under supersonic treatment led to quite an unexpected discovery: it was found that supersonics not only causes oxidation of various chemical compounds, but in some cases causes the direct opposite, i.e., reduction.

Thus, for instance, under the action of supersonic vibrations a solution of mercuric chloride rapidly becomes turbid. The turbidity is caused by the reduction of the mercuric chloride to an only slightly soluble compound—calomel (mercurous chloride), which precipitates out of the solution.

The precipitate can be dissolved again by adding a chemical oxidizer which will change the calomel formed back into mercuric chloride.

This proves that supersonics had caused a chemical change opposite to that of oxidation, viz., reduction.

What is the reason for chemical changes taking place under the action of supersonic waves?

ELECTRICAL CHARGES AND BUBBLES

The rarefactions arising in a powerful supersonic wave, as we have already mentioned, may be so great that the liquid cannot withstand them and is ruptured, forming numerous microscopic bubbles. Cavitation occurs.

The bubbles formed during cavitation contain not only air and water vapour, but tiny droplets of water as well, torn away from the surface of the water at the moment of rupture.

A large number of observations show that the walls of the cavitation bubble and the droplets inside it bear unlike electrical charges. When the bubbles are compressed their dimensions decrease abruptly, and the charges are

Fig. 26 Cavitation bubble

trapped on very tiny bubbles. This greatly increases the electrical tension and electrical discharges resembling microscopic flashes of lightning occur between the walls of the cavitation bubbles and the droplets inside them (Fig. 26).

These electrical discharges are the main cause of the chemical effect of supersonics.

The ability of electrical charges to bring about chemical changes can also be observed in everyday life. Thus, during thunderstorms a peculiar odour usually appears in the air, due to the presence of a certain gas, called ozone, which forms under the action of the electrical discharges of lightning.

The electrical discharges which take place in cavitation bubbles cause complex chemical transformations.

The water molecule, which consists of two atoms of hydrogen and one of oxygen, decomposes into a hydrogen atom and a hydroxyl radical, made up of one oxygen atom and one hydrogen atom.

Whereas the water molecule is chemically quite inactive, the hydrogen atom and the hydroxyl radical enter into chemical reactions very readily. That is why the free iodine is liberated from the potassium iodide solution, and the calomel formed in the mercuric chloride solution.

Besides, water usually contains a large quantity of dissolved gases, mainly oxygen and nitrogen. Pour a glass of cold water from the tap, let it stand for a while in a warm room, and you will see that as soon as the water warms up the walls of the glass get covered with bubbles of gas liberated from the water.

Under the action of the electrical discharge which takes place in cavitation bubbles the molecules of these gases pass into a peculiar "active" state and enter readily into various chemical reactions.

The interactions among the active molecules of the gases dissolved in the water and the particles formed as a result of the decomposition of the water molecule, lead to the formation of new chemical compounds. Although the quantity of these substances is very small, chemists have, nevertheless, succeeded in determining their composition. The most important of them are hydrogen peroxide and nitric acid.

The hydrogen peroxide is one of the main causes of the oxidizing effect of supersonics, such as, for instance, the decomposition of potassium iodide.

Recently the decomposition of potassium iodide has found a new interesting application: it is used to make supersonic waves visible.

For this purpose a special sound-sensitive solution is prepared, containing starch, potassium iodide and very small quantities of other substances to increase the sensitivity of the solution to sound.

Under the action of supersonic waves free iodine is liberated from the potassium iodide, the iodine reacts with the starch, turning the entire liquid dark blue.

If we prepare a set of cells after the fashion of a honeycomb and fill them with a sound-sensitive solution, we get a supersonic raster. This raster enables us to trace the propagation of the supersonic waves by placing it in their path. Wherever the waves enter the cells, they colour the solution in them, and the boundaries of the supersonic ray are sharply defined.

Fig. 27 shows a photograph of a supersonic wave (the dark rectangle).

If an obstruction, such as an ordinary cork, is placed in the path of the supersonic wave, it will give a sound shadow. In the cells of the raster covered by the shadow region no iodine will be liberated, and the solution will not turn blue. Fig. 28 is a photograph of such a sound shadow (the light rectangle) on the background of a raster turned blue under the action of supersonics.

At first there was a tendency to attribute all the chemical effects of supersonics to a certain single cause, but attempts to do so were fruitless. Supersonic sounds propagated through a liquid excite quite a number of phenomena, each of which may result in chemical change, so that it would be a mistake to try to explain all the effects of supersonics by a single mechanism.

Although the electrical discharge in the cavitation bubbles is the main reason of the chemical effects of supersonics, it is not the only one. Collapse of cavitation bubbles, as we know, gives rise to immense pressures, amounting to thousands of atmospheres. Such an increase in pressure is accompanied by a considerable rise in temperature. Although these high pressures and temperatures are limited to microscopic volumes of the liquid, just the same they may cause chemical changes.

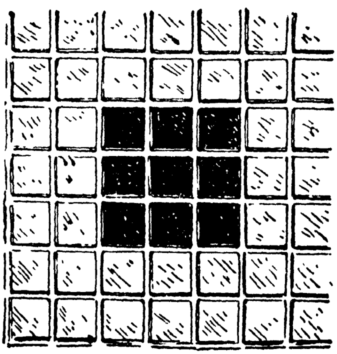


Fig. 27. A supersonic raster

Vibrations of tiny air bubbles at resonance frequencies equal to the fre-

quency of the sonic wave also contribute greatly to the chemical effects of supersonics.

It has been shown recently that supersonics can cause certain chemical changes even without cavitation, only its action in these cases is considerably weaker.

GIANT MOLECULES

In recent years articles made of rubber and various plastics have found wide application in engineering and in everyday life. The molecules of these substances are very large. For this reason they have come to be known as macromolecules or giant molecules. Macromolecules form as a result of polymerization, i.e., the combination of a large number of smaller molecules. Polymerization is one of the most important reactions in the chemical industry.

In some cases it takes place only in the presence of free radicals. We have seen above that supersonics causes the appearance of free radicals, and this suggested the idea of employing it to accelerate the reaction of polymerization. Recently this idea was confirmed experimentally.

For the investigation a substance was selected whose molecules would grow larger only in the presence of free radicals. A special method of purification was used to obtain an aqueous solution of the substance, free of radicals. The solution was kept for six months without any changes taking place in it. But when it was subjected to the action of powerful supersonic vibrations, the solution polymerized immediately.

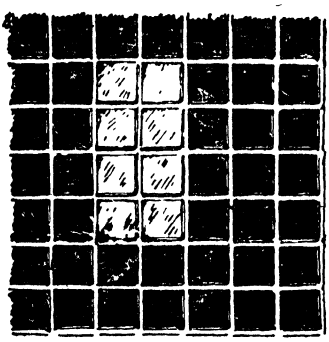


Fig. 28. Shadow of a cork on a supersonic raster

The reader will naturally be interested to know how it is possible to follow the changes in the dimensions of molecules, which are too small to be seen even under the best microscope.

This can be done by making use of the relationship between the viscosity of the solution and the size of the molecules dissolved in it.

The larger the molecules, the higher the viscosity of the solution.

In 1950 the influence of supersonic vibrations on the polymerization of styrene and butadiene was discovered. This reaction forms the basis of the production of one of the types of synthetic rubber, and is therefore of special interest. It was found that if styrene is treated with intense supersonic vibrations under a pressure of 4 to 5 atmospheres, the polymerization reaction is greatly accelerated. Fig. 29 illustrates the influence of supersonics on the polymerization of styrene. The yield of the finished product is plotted against the time of treatment. The intensity of the vibrations was 0.03 watts per cu.cm. of substance treated. The lower curve refers to a control sample which was not subjected to the action of supersonic waves. It can readily be seen that forty minutes' treatment doubles the yield of the finished product.

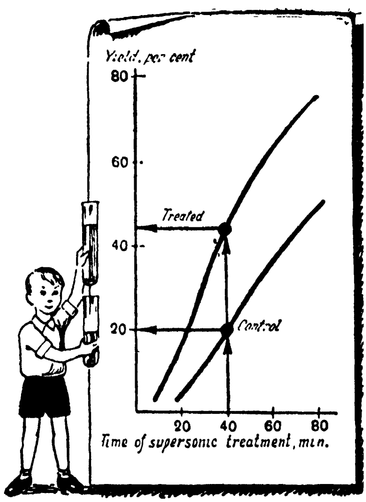


Fig. 29. Acceleration of the polymerization of styrene under supersonic treatment

Acceleration of the growth of large molecules by the action of supersonic waves is of great importance. But supersonic irradiation sometimes causes other phenomena, which have to be taken into account.

DUALITY OF THE PROPERTIES OF INAUDIBLE SOUNDS

Supersonic sounds singularly combine opposite properties. On the one hand they accelerate polymerization, and on the other, break up large molecules, forming particles of much smaller size. Chemists call the latter process depolymerization.

If a jelly-like solution of gelatin is subjected to the action of supersonic waves, its viscosity rapidly decreases and the jelly begins to flow. However, if the supersonic treatment is discontinued, the liquid solution will again become a jelly after some time.

The gelatin solution has the nature of a jelly due to its possessing a definite structure. The long thread-like gelatin molecules, which become entangled in their movements, form a sort of skeleton or framework, within which the solvent, water, is contained. As the forces holding the gelatin molecules in the framework are not very strong, the supersonic vibrations break up the skeleton, and the solution acquires fluidity. When the influence of the vibrations is removed, the gelatin molecules again get entangled as a result of their thermal movements, rebuilding the destroyed framework and, hence, the viscosity.

Powerful supersonic vibrations are capable of lowering the viscosity of the solution of a high molecular substance to such an extent that it is no longer recovered after the sound is removed.

Fig. 30 shows the change in the molecular weight of polystyrene dissolved in toluene. Under the action of supersonics the immense polystyrene molecules break up rapidly.

The splitting of molecules under the influence of supersonics is due mainly to cavitation.

Let us examine the collapse of a cavitation bubble in greater detail.

The surface of the bubble formed within the liquid tends to contract, just like a stretched rubber film. For this reason, as soon as the rarefied zone in the sonic wave is replaced by a compressed zone, the bubble collapses.

One of the remarkable properties of the bubbles formed in the liquid is that the smaller the bubble, the greater the tension of its walls.

Therefore, just before it closes up, i.e., at the moment when the bubble reaches its ultimate smallest size, the pressure within it grows to a tremendous value.

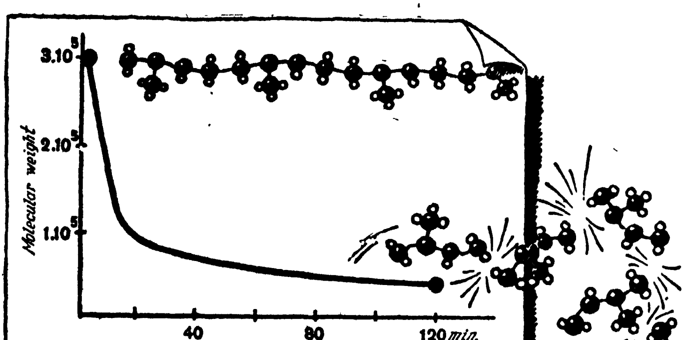


Fig. 30. Supersonic depolymerization

The collapse of the cavitation bubbles and the attending rise in pressure are precisely what break up the macromolecules.

In some cases the molecule may be split by supersonics without cavitation. In an irradiated solution the bulky molecules which go to make up plastics are surrounded on all sides by the small molecules of the solvent. Due to their great size macromolecules are not very mobile; one might say, they are rather clumsy. Under the action of supersonic waves the macromolecules cannot keep up with the vibrations of the solvent molecules in these waves, so that the latter molecules scurry about the former. Friction arises between the molecules of the solute and those of the solvent, just as in the movement of any body in a viscous liquid. Calculation shows that the friction is often high enough to break up the macromolecules.

If the wavelength of the supersonic wave is very small, one part of the giant molecule may happen to be in a compression zone, while the other is in a rarefied zone. In this case there also arises a rupturing stress which may result in the thread-like molecules breaking up.

The same properties of supersonic sound that cause chemical changes account also for another interesting phenomenon called sonic luminescence.

A MYSTERIOUS GLOW

Perform the following experiment. Fill a small thin-bottomed cylinder with pure water. Then place the cylinder in a bath of transformer oil with a quartz plate vibrator in it. Darken the room and when your eyes get used to the darkness switch on the supersonic generator and subject the water to the action of intense supersonic waves. As

soon as the supersonic vibrations reach the water you will observe a narrow glowing band, which usually arises at the bottom of the vessel, and less frequently at the top. The glow grows more intense, spreads and soon fills the whole vessel. For some time after this the glow remains unchanged, then it begins to grow weaker and suddenly disappears.

The glow in called sonic luminescence.

In studying sonic luminescence the Soviet scientists V. L. Levshin and S. N. Rzhevkin discovered many interesting things. It was found that a luminescence of the same kind as in water could be caused by supersonic irradiation of glycerin or sulphuric acid.

But when experiments were made with organic liquids, such as benzene, ethyl alcohol, nitrobenzene, no luminescence was observed.

The scientists also found that if the temperature of the liquid was raised or if it was saturated with carbon dioxide the glow disappeared.

At the same time the presence of such substances as common salt, calcium chloride or sulphuric acid in the water had no effect on the nature of the glow.

What is the cause of this glow?

You have probably already guessed that the source of the glow are the cavitation bubbles. The gases and vapours filling these bubbles glow under the action of an electrical discharge, just like the neon tubes of a light advertisement.

This clears up many things.

The common salt or sulphuric acid dissolved in the water are not volatile, and are not present among the gases filling the cavitation bubble; therefore, they do not affect the glow.

On the other hand, carbon dioxide is volatile, and when it gets into the cavitation bubble it extinguishes the glow.

Higher temperature increases the amount of water vapour inside the bubble, thus impeding the appearance of the electrical discharge and preventing luminescence.

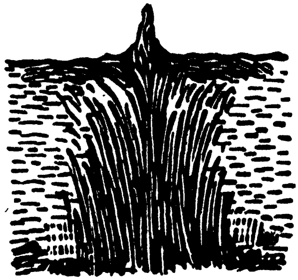


Fig. 31. A supersonic photograph

It is considered that the luminescence of water under supersonic treatment explains the darkening of photographic plates by supersonic beams.

If an unexposed photographic plate is submerged in distilled water, subjected to the action of supersonics and then developed, the plate will be found to have darkened as if it had been exposed. The greater the intensity of the sound, the darker the plate. There have been attempts to make use of this fact to obtain images of sonic waves. Fig. 31 is a supersonic photograph of this kind, representing a focussed wave. The exposure time was 20 minutes.

It should be emphasized that there was no lighting when this photograph was taken; the plate was darkened by supersonics alone.

Now let us turn to an interesting attempt to apply the chemical effect of supersonics in practice.

SUPERSONICS SUBSTITUTES TIME

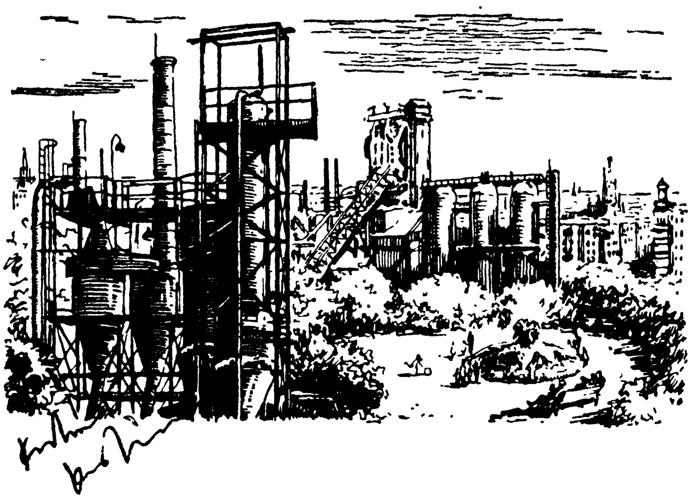
The temperature rise which accompanies the absorption of supersonic sound and the peculiar nature of the movements of the separate particles in a supersonic wave result in the fact that powerful supersonic sounds cause accelerated "aging" of substances treated with them.

As we know, the best brands of whisky and wine are

specially "aged" to give them the flavour that is prized in them.

Aging is a slow process, but the aging of whiskies and various liqueurs can be accelerated by subjecting them to supersonic treatment. It was found that this considerably improves the quality of the whiskies and liqueurs. After supersonic treatment the beverages acquire qualities which without the help of supersonics can be attained only by very prolonged aging under special conditions. However, supersonics is not used to age wines, because in many cases it lowers their quality by increasing the acid content.

In 1953 the Soviet scientists F. K. Gorsky and V. I. Yefremov discovered that supersonic vibrations are capable of accelerating the aging of solids as well as liquids. According to their experiments, the aging of aluminium alloys, which enables them to acquire the necessary hardness after tempering, takes place about 80 times as fast under the action of supersonics as under normal conditions. This is a discovery of great practical importance.



Chapter 5

ONE OF MAN'S HELPERS

SOUNDS THAT CRUSH

We have seen that supersonic sound is capable of breaking up the tiniest particles of substance—molecules. It is natural to expect that powerful sounds can be used also to disperse various liquid or solid bodies consisting of many billions of molecules.

If mercury and water are placed in a test tube the mercury, which is the heavier of the two, will sink to the bottom, while the water will remain on top. If the test tube is shaken the mercury may be broken up for a moment into tiny droplets which mix with the water. But as soon as the shaking is stopped the droplets of mercury collect at the bottom and merge into a single large drop. Two layers bounded by a sharply defined border-line again appear in the test tube. Now let us try placing the test tube in a pow-

erful supersonic fountain. In only a few minutes we shall have a homogeneous grey mass with no discernible separate layers in it. The mercury droplets are now mixed uniformly with the water, just as the tiny droplets of fat are mixed with water in milk.

Just the same, this is no true solution in which the dissolved substance is broken up into molecules. Although supersonics breaks the mercury up into tiny particles, they are still very much larger than molecules. With a good microscope the separate droplets of mercury can be distinguished and measured. They are but a few hundred thousandths of a centimetre in diameter. Such droplets consist of hundreds of thousands of molecules, but they are small enough not to sink immediately to the bottom of the test tube, and they settle very slowly. Even after 24 hours a comparatively large number of fine particles will not have settled. Such an analogue of a solution is called an emulsion, if the dispersed substance is a liquid; the process of dispersion is called emulsification. Various emulsions are used in engineering, medicine and in everyday life for a great many different purposes.

So-called bituminous emulsions are widely used in road construction. A very great variety of emulsions is used in the food industry—various sauces and creams, fillings for candies, and margarine, which is a cooled emulsion of butter, fats and sour milk. Emulsions are widely used in the pharmaceutical, textile and leather industries, in agriculture, etc.

Industry is interested in producing emulsions as rapidly as possible.

To date scientists have prepared a great number of various emulsions with the aid of supersonics. Benzene, paraffin and various oils are readily dispersed in water. Oil emulsions are especially easy, and take very little time to

produce. They are very stable and change but insignificantly in time.

Figure 32 shows some motion picture photographs taken of the formation of an emulsion of oil in water. The oil is delivered through a tube to a supersonic vibrator. Under the action of the supersonics it is broken up into very small droplets. The resulting emulsion can be seen in the photographs as a gradually increasing cloud. By the growth of the white cloud we can see how rapidly the emulsion is formed under the action of supersonics (the time intervals between photographs are fractions of a second).

The rapidity of emulsification under the action of supersonics may be of great practical importance.

Supersonic dispersion is mainly due to cavitation. The propagation of the supersonic wave leads to vibration of the walls of the vessel containing the liquid to be dispersed. These vibrations also promote the formation of the emulsion.

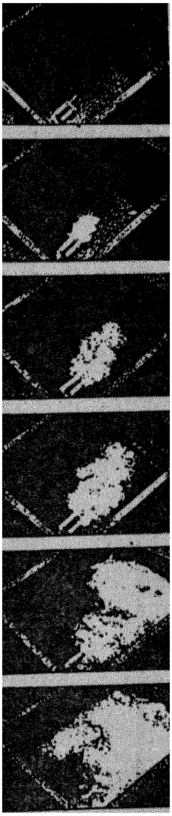


Fig. 32.
Formation of an oil emulsion in water

Supersonics can be used also for the dispersion of solids to form suspensions, i.e., mixtures of finely ground solids with liquids. Various paints, some medicinal preparations, lubricants for the friction parts of machines and other widely used substances are suspensions. Solids in which the forces of cohesion are not very great, such as gypsum, mica, sulphur, as well as various solid organic compounds, for instance, naphthalene or camphor, can read-

ily be dispersed by supersonics. Metals are more difficult to disperse, but nevertheless suspensions of many metals in water and oil have been obtained.

In this case dispersion also occurs as a result of cavitation. The immense pressures which arise when the cavitation bubbles collapse act like microscopic impacts in destroying the solid.

As we know, cavitation is due not only to the propagation of supersonic sound. It is also caused by the motion of a ship's propeller or of the blades of a hydroturbine. The cavitation bubbles formed in these cases also collapse rapidly, corroding the propeller and blade surfaces. This proves that one of the causes of the destructive action of supersonics has been pointed out correctly.

It should be noted that supersonics will disperse a solid to a very fine state, but the amount of pulverized substance is usually insignificant. Indeed, in order to disperse only one gramme of nickel using a supersonic generator of medium power a plate four square centimetres in area would have to be subjected to continuous supersonic treatment in the course of a month.

Hence, when it is desired to obtain a comparatively large quantity of pulverized substance, special methods must be employed.

For instance, a piece of silver may be dispersed by placing it in a bath filled with a solution of a suitable salt of the metal, in our case, a silver nitrate (Fig. 33). A special metallic plate is lowered into the same bath. The silver is connected to the positive pole of a battery, and the plate to the negative pole. Under the action of the electric current the piece of silver dissolves, and at the same time an equal quantity of silver deposits from the solution as tiny crystals on the metallic electrode. If the bath is placed

over vibrating quartz plates and a powerful supersonic beam passed through it the tiny silver crystals will be torn off the electrode, and an extremely fine-grained suspension will result.

This arrangement can be used to produce suspensions of a great variety of metals. The apparatus is simple in design and of high capacity.

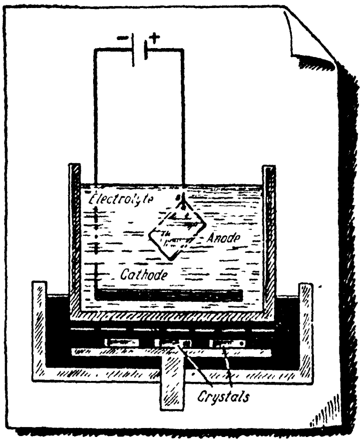


Fig. 33. Apparatus for supersonic comminution of solids

By combining chemical reactions with supersonics in a manner similar to that described above, fine precipitates of a wide range of various substances can be obtained.

SUPERSONICS SAVES HUMAN LIVES

Supersonic dispersion has become an especially important factor in the production of certain medicines. There are medicines which are insoluble in water and have to be administered as emulsions or suspensions. Such, for instance, is camphor. The insolubility of camphor in water makes it impossible to inject it directly into the blood of the patient so that it should reach the heart more quickly. Camphor oil injected into a vein obstructs the blood circulation and is usually fatal to the patient.

With the aid of supersonics scientists have broken up the camphor oil into such tiny particles in water that the resulting emulsion can be injected harmlessly directly into the patient's blood.

Lately medicinal substances related to sulphonamides have become very important. Many people use sulphonamide emulsions, but few are aware that supersonics is often used to prepare them. Experience has shown that sulphonamide emulsions obtained by supersonics are much more effective than those prepared in the usual manner.

Supersonics not only makes it possible to prepare medicines with better curative properties, but also opens up new ways of introducing them into the patient's organism. With the help of supersonics various substances can be introduced through the skin of the patient. Supersonic sound forces the substance in through the pores of the skin without injuring it. This property of supersonic sound may turn out to be of great importance in medicine.

The use of supersonics for the production of new medicinal preparations will doubtlessly keep increasing, helping in the noble struggle to save human lives.

SCIENCE AND PRACTICE

Supersonic dispersion is of unquestionable interest for many branches of industry, for instance, in the production of photographic plates and films. The sensitized layer of a photographic plate consists of gelatin with inclusions of very small particles of silver bromide. Under the action of light the silver bromide particles decompose, giving rise to the photographic image.

The quality of photographic plates depends on how fine the silver bromide has been ground. The smaller the grains in the photographic emulsion, the greater the enlargement the negative will permit. Fig. 34 shows photomicrographs of silver bromide suspensions: *a*—obtained in the usual

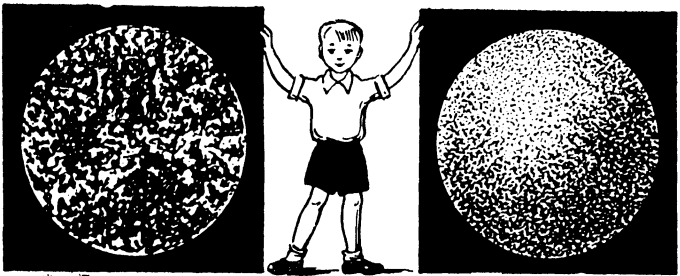


Fig. 34. Emulsions obtained in the usual manner and with the aid of supersonics

manner and *b*—by supersonic dispersion. Suspensions produced by supersonics are fine-grained and very uniform, Highly sensitive plates with remarkable photographic properties have been produced by using supersonics.

Supersonics have been employed successfully to pulverize many organic dyes. Such suspensions retain their dyeing (colouring) properties for a long time. In preparing suspensions of this kind so-called stabilizers are added to keep the suspension from settling. Sometimes the suspensions obtained by supersonics are stable enough without the addition of stabilizers.

Supersonic dispersion can be used in the dairy industry. In making ice-cream and sometimes in the treatment of milk a special operation called homogenization is employed to disperse the globules of butter-fat and produce a uniform mass. Homogenization is usually carried out under a pressure of 200 to 250 atmospheres. Supersonics has been employed successfully for the same purpose.

In some cases low-grade liquid motor fuel can be improved considerably by dispersing a small quantity of water through it in the form of very small droplets. Superson-

ics has been suggested as an agent for the production of such emulsions. Fuel emulsions can be employed in blast furnace processes and in steel smelting. Supersonics can be used to disperse aqueous solutions of various substances through the fuel. This makes it possible to study the influence of various admixtures on the combustion of the fuel and to alter the properties of the latter.

WASHING WOOLLENS WITH SUPERSONICS

Recently a new application of the destructive properties of supersonic sounds was suggested, consisting in the removal of foreign particles sticking to fabrics. To put it more simply, supersonics was used for washing.

Supersonic washing was such a success that very soon several systems of supersonic washing machines made their appearance. It was found that ordinary audible sounds could be used successfully to operate these machines. One of the widely used sonic washing machines consists of a steel cylinder which can be fastened to the wall of a tank or to a bucket of soapy water in which the dirty clothes are placed. The cylinder has a powerful magnet inside which vibrates a rod with a membrane on its end shaped like a double convex lens. The membrane is immersed in the water with the dirty clothes. The rod vibrates 100 times per second. By moving back and forth, the membrane causes intensive vibrations in the soapy water.

The particles of dirt sticking to the fabric were torn away and the fabric thus cleaned. The washing took very little time.

Not long ago Soviet scientists developed a method for washing raw wool supersonically. Wool is usually greatly contaminated with grease and other organic substances. In

order to remove the grease, the wool has to be washed in a soapy solution containing a large amount of alkali. This lowers the technological properties of the fibre. With supersonics the washing can be performed in an almost neutral solution, so that the fibre fully retains its quality. It should be mentioned also that the hydrogen peroxide which forms as a result of supersonic treatment improves the appearance of the wool by bleaching it. It is very important, besides, that various microorganisms are destroyed in the course of supersonic washing, including the spore-bearing bacteria always present in unwashed wool. Nor should it be forgotten that supersonic washing reduces soap and alkali consumption.

The above properties of supersonic sounds were utilized in tools for removing scale in steam boilers. For this purpose a special projector installed in the boiler directs an intense supersonic wave at the part of the boiler's surface where the bulk of the scale has formed. The powerful vibrations tear the scale away and clean the surface.

In recent years the supersonic method of cleaning the surfaces of various metals has gained great importance. This method is used successfully for removing contaminations from the metal parts of radio valves, for cleaning watch bearings, midget gears, complex transmissions, etc. In some cases the cleaning is effected by supersonics dozens of times as fast as by usual methods.

THE SUPERSONIC SOLDERING IRON

The destructive action of supersonics can be utilized to make special soldering irons which are of great importance in industry.

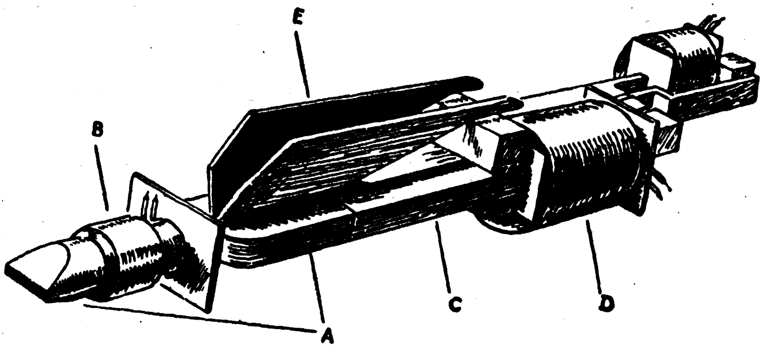


Fig. 35. A supersonic soldering iron

One of the inconveniences of using aluminium and its alloys is that nothing can be soldered by ordinary methods to articles or machine parts made of this metal. No matter how we try to clean the spot to be soldered by mechanical means or with chemical cleaning agents, the solder will not adhere to the surface of the metal and the joint will be very weak. This is due to the fact that aluminium oxidizes very rapidly and the thin oxide film which forms prevents access of the solder to its surface. True, aluminium articles can be soldered with special solders, but they are more difficult to use than ordinary solder.

Aluminium articles can be soldered in the usual manner if the joint is subjected to the action of powerful supersonic vibrations while the soldering is being performed. The supersonic vibrations tear the oxide film off the surface and the solder adheres firmly to the aluminium. It is convenient to destroy the film with vibrations of a frequency close to that of audible sounds.

In the supersonic soldering iron (Fig. 35) the rod *A* which does the soldering is welded together with the heater *B* to a magnetostrictive vibrator *C*. The vibrator is lo-

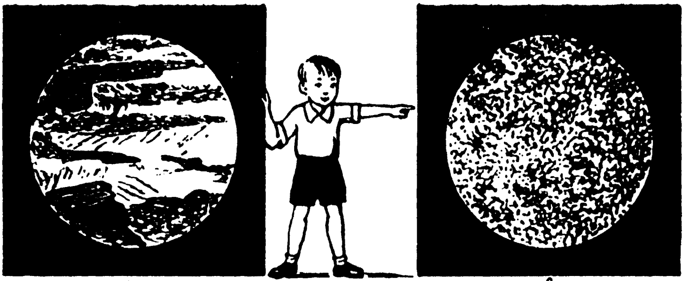
cated inside a coil D of insulated wire through which high-frequency alternating current is passed. The high-frequency vibrations of the magnetostrictive core are transmitted to the working part of the soldering iron and thence to the solder. These supersonic vibrations destroy the oxide film. The special "ribs" E are for cooling the non-working part of the soldering iron.

Small aluminium articles can be soldered by means of the supersonic soldering iron without preheating. Large objects have to be preheated because they cool down rapidly due to the high heat conductivity of aluminium, and are difficult to keep hot with the soldering iron. If the surface film is weak, as is the case, for instance, with iron, the soldering can be done without preliminary cleaning. By this method rusty iron objects can be soldered quite reliably.

By using supersonics to remove the oxide films, aluminium sheets and various aluminium machine parts can be tin-plated.

The Soviet scientist Sergei Yakovlevich Sokolov studied the action of powerful supersonic vibrations on solidifying melts. He found that the use of supersonics makes the crystalline structure of the ingot very uniform and fine-grained. Fig. 36 shows micro-etchings of melts of cadmium: *a*—solidified under ordinary conditions and *b*—when crystallization took place under supersonic treatment. The figure shows graphically the finer grain and higher homogeneity of the structure when formed under the influence of supersonic waves. At the same time the melt is freed of air bubbles, which could have led to the formation of cavities in the castings had they remained in the metal.

Another important point is that in some cases supersonic treatment cuts down the time of crystallization 35 per cent.



a б

Fig. 36. Cadmium micro-etching viewed under the microscope

The dispersive action of powerful supersonic vibrations has been utilized in the design of a peculiar "supersonic reciprocating drill." In this instrument a tip made of a special alloy is fitted to the end of a magnetostrictive vibrator furnished with a metal cone. Delivering a suspension of a very hard substance, e.g., boron carbide, to the tip, this chisel can be used to punch holes of any shape desired and even to machine ceramic surfaces.

Supersonics is especially useful for treating very hard materials, such as precious stones and certain minerals. By using special vibrating tips die shapes with highly finished surfaces can be made.

Supersonic vibrations will travel along a thin wire, following its shape even if it is bent. This property of the vibrations makes it possible to drill holes with fantastically bent axes by means of supersonic bits. Hitherto there was no tool that could do this.

A special supersonic bit is a valuable aid in the hands of the dentist. With this drill or "cavitron," as it is called, the dentist can rapidly make a very thin channel in the tooth, drilling away only the part of the dental substance which has to be removed. Supersonic treatment

considerably reduces the unpleasant sensations usually associated with having one's teeth filled.

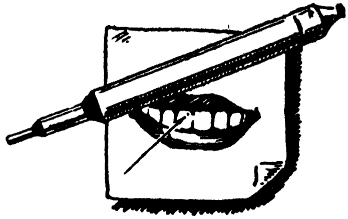


Fig. 37. The "cavitron"—a supersonic dentists' drill

As we have already seen, supersonic sounds are capable of causing opposite effects; thus, if they oxidize substances in some experiments they reduce them in others; sometimes they accelerate polymerization, at other times they cause depolymerization, etc. No wonder, therefore, that along with their capacity for dispersion they are capable also of accelerating the opposite process, that of the coagulation of small particles into larger ones.

PURIFYING THE AIR WITH SUPERSONICS

Factory smoke, as we know, consists of tiny particles of solid and liquid substances mixed with air. Under the action of sound smoke quickly precipitates. The same is true of mists, which consist of tiny droplets suspended in the air. The separate particles stick together when they collide, forming heavier particles which begin to settle. This growth of particle size is called coagulation or agglomeration.

The ability of supersonics to cause coagulation is very high: a thick white smoke of magnesium oxide settles almost instantly under supersonic treatment. Fig. 38 shows the changes that take place in tobacco smoke under the action of supersonics. Photograph *a* is the smoke before supersonic treatment, *b* shows the initial stage of the treatment. In photograph *c* large parti-

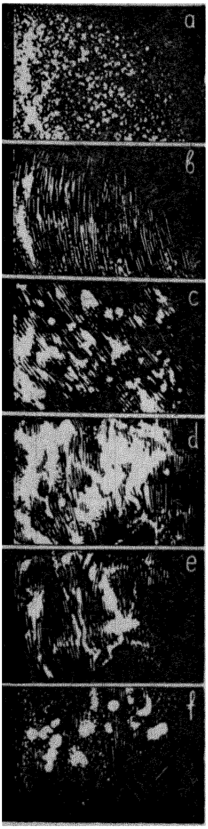


Fig. 38. Supersonic coagulation of tobacco smoke

cles can be seen to have formed, photographs *d* and *e* show the intricate movements of these large particles. In the last photograph, *f*, we see separate large flakes which settle rapidly.

What is supersonic coagulation?

A sonic wave passing among particles of smoke or mist gives rise to attractive forces between them.

To get an insight into the nature of these forces, recall an experiment often shown during physics lessons at school. If two light plastic balls are suspended on strings at a small distance from one another (Fig. 39) and a current of air passed between them the balls will approach each other until they collide. The same phenomenon occurs if the air is left alone and the balls are moved. Similar forces, arising in the sonic wave, make the smoke particles approach one another, collide and stick together, forming larger aggregates.

Besides, the larger smoke or mist particles lag behind the smaller ones in their movements, due to their greater mass, increasing the number of collisions which result in the formation of large particles.

Sonic agglomeration has already found application in engineering. Supersonics is employed to catch tiny particles of carbon black, to precipitate sulphuric acid mists in the process of its manufacture, etc.

In this way the air of cities and factory settlements can be purified from the smoke thrown out by the factory

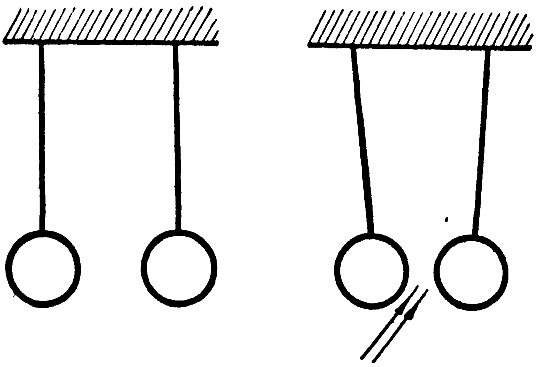


Fig. 39. Balls in an air flow

stacks. This method will unquestionably acquire great importance, because it can be used to catch particles which pass easily through ordinary filters.

There has been a suggestion to employ powerful sonic waves at aerodromes to coagulate mists and thus facilitate landing for aeroplanes. In this case audible sounds must be used, because in the air supersonic sounds damp very quickly and are effective over only a comparatively small distance from the source.

The elimination of dust and tiny droplets of various chemical substances thrown into the air by factory stacks is of immense importance. Dust is harmful not only to the surrounding population, but to animals and plants as well. A great deal of attention is devoted in the Soviet Union to the elimination of industrial dust.

The powerful supersonic or sonic vibrations used in industrial plants for the precipitation of fine particles are obtained by means of special sirens.

A powerful supersonic siren consists of two disks, one stationary, called the stator, and the other revolving at high speed, called the rotor.

The revolving disk has teeth on its circumference opposite perforations in the stationary disk. As the rotor spins around its teeth and the spaces between them come alternately past the perforations in the stationary disk. If compressed air is delivered to the teeth of the rotor as shown in Fig. 40, an intermittent jet of air, interrupted by the teeth of the spinning rotor will come out of the perforations of the stator. This will cause alternate compressions and rarefactions in the air surrounding the siren, i.e., will give rise to a sonic wave. A supersonic siren with a disk having 110 teeth did 250 revolutions per second and gave rise to a wave with a frequency of about 27,000 vibrations per second.

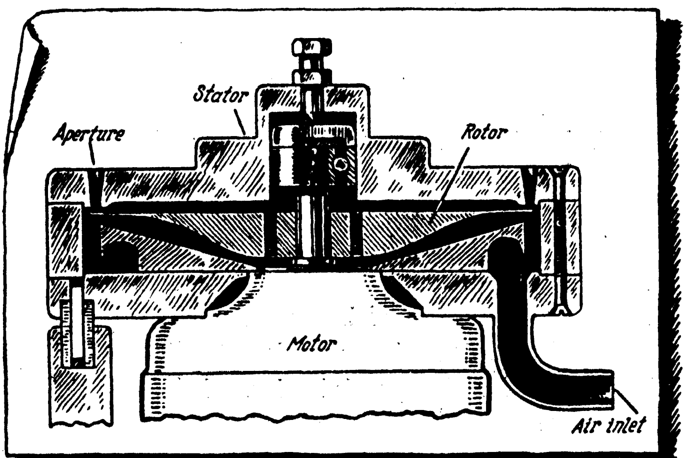


Fig. 40. Schematic drawing of a supersonic siren

Sirens can be used to obtain very intensive sonic and supersonic vibrations of a power of several kilowatts. These vibrations are so powerful that a piece of cotton wool placed in the path of the sonic wave flares up in a few seconds as a result of absorption of acoustic energy and transformation of the latter into heat.

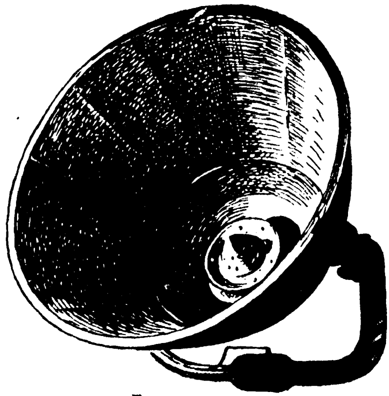


Fig. 41. Reflector for focussing supersonic waves

Sonic and supersonic waves produced by sirens for air purification are converged into narrow beams by means of special reflectors resembling searchlight mirrors (Fig. 41). The siren is installed at the top of a special tower and the sonic wave is directed downwards.

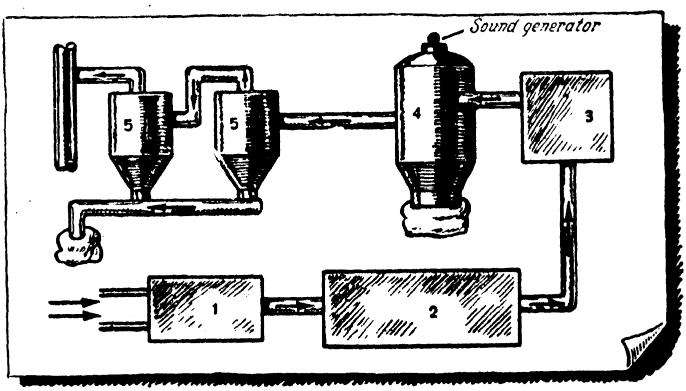


Fig. 42. Scheme of an arrangement for supersonic precipitation of carbon black

A diagram of an arrangement for the collection of carbon black is given in Fig. 42. The mixture burnt to produce the black goes through the preheater *1* into the reaction chamber *2*. The carbon black formed passes through the cooler *3* into the sound tower *4* at the top of which the siren is installed.

It has been established that the size of the particles should be increased only up to the point where their settling velocity reaches half a centimetre per second. There is no use increasing the particle size above this value, because large aggregates are broken up again by the sonic wave.

The air with the enlarged particles passes into ordinary dust separators (cyclones) *5*, where most of the carbon black is precipitated.

The most effective sound frequency for the precipitation of the particles depends on their size, and is to be found by experiment.

The use of sonic precipitation is advantageous if the diameter of the particles to be caught is less than one-thousandth of a centimetre and their content not less than 4 to 5 grammes per cubic metre.

Not long ago supersonic sirens were employed successfully in engineering to glaze porcelain and ceramic wares. It is thought that the action of the sirens is not limited only to atomizing in this case, considerable importance being attached also to the fact that the substance becomes hot under the influence of the supersonic waves.

SUPERSONICS HELPS TO INTENSIFY PRODUCTION

Supersonics is capable of accelerating or, as we say, intensifying many important industrial operations. At chemical plants it is very often necessary to extract valuable

substances dissolved in some liquid. Sometimes the liquid is mixed for this purpose with another liquid which does not dissolve in it but which dissolves the substances to be extracted. This operation, called extraction, is carried out in extraction towers with special packings or with porcelain rings.

The lighter liquid enters the column from below and the heavier liquid from above. The counterflow thus set up inside the tower mixes the liquids thoroughly and the dissolved substance passes from one of them into the other. The more difficult it is to extract the substance, the longer the liquids must remain in contact with one another and the higher the tower must be. It was found, however, that the rate of extraction could be increased considerably by setting the tower into vibration. When the tower and the liquid in it are in a state of vibration extraction is so greatly accelerated that the height of the tower needed for practically complete extraction of the substance is only one-third of the height of a non-vibrating tower.

Supersonics is even more effective in extracting valuable substances contained in the cells of animal and plant organisms. With its aid the recovery of valuable proteins from yeast cells can be increased and the evolution of active enzymes is accelerated. This property of supersonics has already found practical application in beer brewing. According to the brewers, supersonic treatment of hot mixtures to which hops have been added saves 40 per cent of the hops owing to fuller extraction of the substances needed for brewing.

Great prospects are in store for the use of the accelerating effect of supersonics in the leather industry. Before being fashioned into pretty shoes and boots the hide of the animal has to be put through a complicated treatment: it is washed with water and alkalis, the hair is removed from

it, then the leather is tanned, coloured, etc. Most of these processes are ordinarily very slow, but supersonics can accelerate them by many times. For instance, a tanning test carried out on a leather sample with simultaneous supersonic treatment took only 18 hours while a control sample tanned without supersonics was ready only in 114 hours. Supersonic treatment guarantees uniform tanning of the entire sample. It is quite probable that supersonic vibrations will be able to step up other processes in the leather industry as well.

Experiments have shown that supersonic and sonic vibrations accelerate the dyeing of various fabrics and may therefore be utilized to intensify dyeing processes. In some cases both supersonic and sonic vibrations can be used with equal success while in others, particularly when refractory fabrics are to be dyed, only supersonic vibrations will do. Sonic vibrations cannot as yet be employed for accelerating dyeing processes on a large commercial scale owing to the absence of adequate apparatus and to the necessity of elucidating certain technical and economical problems connected with the process.

The cause of the accelerating effect of supersonics is not quite clear as yet. It probably lies in the changes taking place in the layer in which two liquids or a liquid and a solid come into contact. These same changes are possibly the reason for the increased rate of heat removal from a hot body by the air surrounding it when the latter is in a state of sonic vibration. Experiments show that all other conditions being equal, the rate of heat removal increases several-fold if the hot body is placed in a current of air in a state of sonic vibration. True, a considerable part in the acceleration of heat removal is played possibly by the currents of air which arise due to the propagation of intense sonic vibrations. The heat removal increases also if the hot

body itself is caused to vibrate. It is assumed that the heated layer adjacent to the body expands, increasing the area of the interfacial surface.

FLUIDIZATION

In recent years, a special process has acquired great importance in various branches of engineering, by means of which finely divided solids can be made to flow through pipes as if they were liquids such as oil or kerosene. This process is known as fluidization.

The importance of fluidization is not limited to the fact that it facilitates the transport of various materials, from solid fuel to grain. It also makes possible many valuable chemical transformations. It is especially important in the refining of crude oil for gasoline production. In one of these processes the so-called catalysts, substances indispensable to the reaction, are kept in a fluidized state.

Fluidization has been employed successfully in other branches of the chemical industry too: in coal gasification, ore roasting, in the preparation of certain valuable chemical products, etc. To fluidize a material it is pulverized and placed on a special grating in not too thick a layer and then a powerful blast of air or some other gas is blown through the layer making the solid particles float, in a sense, in the air. This increases the thickness of the layer of solid material (the "bed"), the solid takes up more volume and the entire mass of the material acquires the ability to flow like a liquid together with the air current.

However, not all materials are easy to fluidize. Sometimes instead of fluidizing the entire layer of material on the grating first rises under the pressure of the air like a piston and then breaks up and falls back in pieces on to the

grating. After this the formerly uniform layer loses its uniformity. Channels are formed in the bed which allow the air flow to pass through freely while the entire mass of the material remains immobile on the grating. Experiment has shown that in such cases fluidization can be achieved by passing intense sonic vibrations through the layer. Of course, rapidly damping supersonic sounds should not be used for this purpose. Quite satisfactory results can be obtained with the aid of sufficiently intense sounds of low frequency, say 50 to 500 cycles per second.

Sonic treatment makes it possible to fluidize even such materials as finely ground gypsum, the particles of which cannot be made to "float" at all under ordinary conditions. Under the action of the sonic vibrations the formerly dense layer of gypsum expands in a few seconds and acquires fluidity.

It is quite certain that supersonic precipitation and collection of finely divided particles will find wide application in various branches of engineering. Together with the biological and chemical effects of supersonics its mechanical action on substances is one of the important fields of the practical utilization of inaudible sounds.

Chapter 6

SUPERSONIC CONTROL

SOUND AS INSPECTOR

Man has long since learnt to use sounds to control the quality of various wares. Even today, before wrapping up the glass you have purchased, the salesman at the store taps it lightly with a stick to determine by the sound whether it is not cracked.

In a similar way the railway inspector checks the wheels of railway waggons by tapping them with a light hammer. The ringing metallic sound becomes a toneless thud if there is a defect in the wheel.

But these methods of control are crude and imperfect.

The nature of the sound can show whether there is a crack in the glass or not, but cannot show whether there are any air bubbles entrapped in its walls.

The most important parts of machines are usually made of metal. These parts are often large in size. Various defects may appear in the process of their manufacture. Castings sometimes have air bubbles or, as they are usually called, gas cavities, inside them. Pieces of slag or stone may have accidentally fallen into the casting mould and thus got entrapped in the metal. In some cases so-called "fatigue" cracks appear in certain machine parts during assembly or when in operation, etc.

Defects of this kind greatly impair the strength of the part, and are absolutely intolerable in responsible parts of machines, such as, for instance, locomotive axles, crank-shafts, aeroplane propellers. Hence, it is quite clear how important it is to reveal hidden flaws in time and separate the good parts from the defective ones.

Soviet scientists employ inaudible sounds for revealing defects.

In our days two methods of supersonic control are used, the method of "through sounding" and the method based on the reflection of supersonic signals.

THROUGH SOUNDING

Irradiation of machine parts with X-rays or the gamma rays emitted by radioactive substances has been employed for a comparatively long time for the detection of defects.

Why, then, was it necessary to use supersonics for the same purpose?

The most powerful X-rays can penetrate only about 8 to 12 inches of metal. Therefore they can be used only for comparatively small parts. Besides, X-rays and gamma rays can detect only relatively large defects. For instance, if

the part under investigation is 8 inches thick, irradiation will reveal cracks not less than 5/32″ wide. Such cracks are very rare. The smaller cracks, usually met with in industry, cannot be detected by X-raying.

It is different with supersonics. Supersonic waves pass through considerable thicknesses of metal without damping.

At the same time the supersonic wave loses a great part of its power if even a thin crack happens to be in its way, so that quite insignificant defects can be detected in this way.

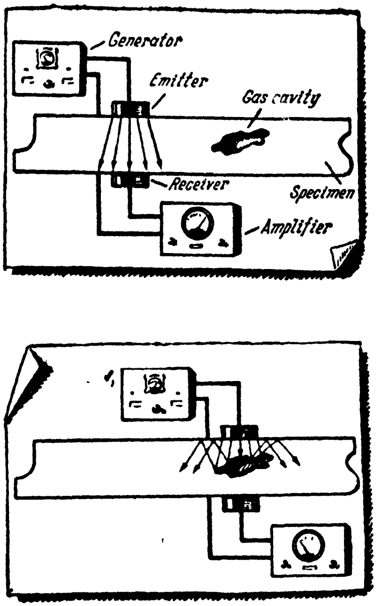


Fig. 43. Through sounding method

The operator inspecting the quality of the product puts the supersonic emitter against one of the surfaces of the specimen under investigation, as shown in Fig. 43. The receiver is applied to the opposite surface, directly across from the emitter.

If there are no defects in the part the supersonic wave moves in a straight line until it reaches the opposite face, the receiver registers the arrival of the supersonic vibrations, and the pointer of the instrument is deflected.

Any defect in the path of the supersonic ray, such as a crack in the metal or a cavity filled with air, being an obstruction to the wave, will keep the sound from reaching the receiver, and the pointer will not be deflected.

This method can be used to detect flaws in parts several yards in dimension, which cannot be inspected by any other means. The quality of joints in multiple trusses has been checked in this way.

But through sounding has a number of shortcomings.

The supersonic wave sent through the metallic part moves in a straight line until it reaches the opposite face; then it is reflected and goes back. On its way back it meets the wave coming from the projector and merges with it. The result is a complex undulation which complicates observations.

The influence of the reflected waves is the main shortcoming of such instruments. Besides, the receiver is influenced by the electromagnetic wave emitted by the supersonic generator. This wave may cause a signal to appear even when there is a defect in the path of the supersonic ray.

Another shortcoming of this method is that, having detected a flaw, we cannot tell how deep it is situated.

Often when inspecting separate parts of assembled machines only one of the faces is accessible, while for the detection of defects the transmitter and the receiver have to be applied simultaneously to two opposite faces.

All this led to the wide use at the present time of another method of control, the detection of defects by reflection.

REFLECTING DEFECTOSCOPE

The reflecting defectoscope invented by S. Y. Sokolov makes use of the same principle as supersonic hydrophones. A very short supersonic signal or impulse, as it is called, is sent through the part under investigation, as shown

in Fig. 44. The impulse *1* goes through the part to the opposite end, to its "bottom," is reflected and returns as an echo *3* to the quartz plate that emitted it. The supersonic echo is made visible by means of an oscillograph, just as in supersonic hydrophones.

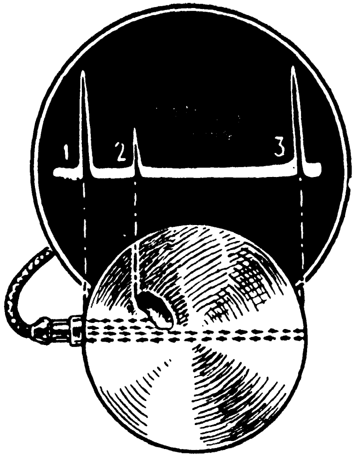


Fig. 44. Scheme of reflecting flaw detector

If there are any cracks or cavities in the path of the ray the shape of the echo-signal *2* changes and in this way the inspector can tell whether the part is defective.

Fig. *a* in Plate III shows the shape of the echo obtained on the screen of the oscillograph in the supersonic investigation of a certain machine part. This figure registers excessive echo-signals (over those for a normal part). When the part was sawn in two the flaw was actually found (*b*, Plate III).

The size of the reflected signal coming back from the defect gives an idea of the dimensions of the latter.

The depth at which the defect is situated can be determined from the distance between the indentations in the ray on the screen of the oscillograph corresponding to the signal emitted and to that received after reflection from the defect.

If there are several cracks or cavities in the part, located one after the other along the path of the supersonic ray, the marks of several echoes will appear on the oscillograph screen in the same sequence as the corresponding flaws are situated in the part.

At present Soviet industry puts out several types of reflecting defectoscopes, with the aid of which various plants and factories keep a close check on the quality of the products they manufacture.

Reflecting defectoscopes can be used to investigate very large parts, about 30 feet in dimension.

Soviet scientists applied very short signals lasting ten-millionths of a second to the detection of defects. This makes it possible to detect very small defects in metallic wares.

It should be kept in mind that supersonic echoes return not only from manifest flaws but from various irregularities as well: from regions where the metal is more friable or from large crystals formed as the metal solidified, etc. In *c*, Plate III, we see the large regular marks corresponding to the repeated return of the echo from the bottom of the part under investigation. The irregularly shaped signals on the same figure are caused by irregularities in the structure of the metal.

A metallic part free from defects of all kinds consists of separate small crystals cohering strongly to one another, and the supersonic defectoscope makes it possible to draw conclusions as to the dimensions of these crystals by the magnitude of the "bottom" signal.

This feature of the supersonic defectoscope is a very important one, because in the manufacture of certain especially responsible parts the size of the crystal grains may be essential, and such a part, if made of coarse-grained metal, may have to be rejected even though it has no cracks or cavities.

If the size of the crystal grains is close to the wave-length of the supersonic ray, the part will not be "transparent" to supersonic sounds, just as a mist consisting of

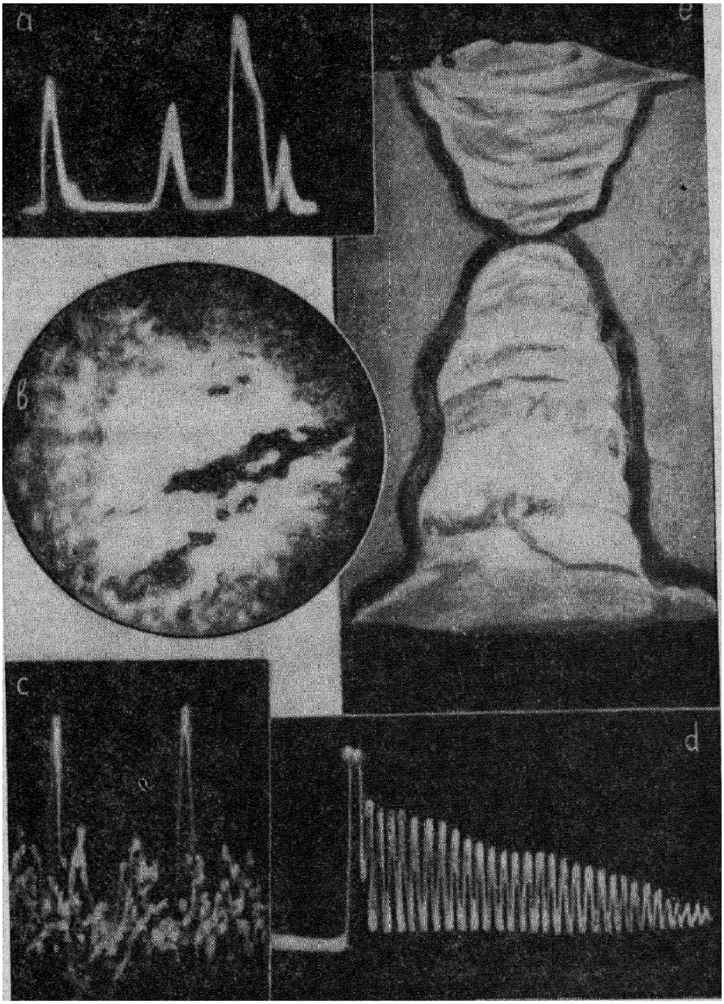


Plate III

a appearance of echo-signals; b—the corresponding defect; c—reflection of an echo by irregularities of the metal; d—repeated echo in a plate; e—defect in a weld revealed by a flaw detector

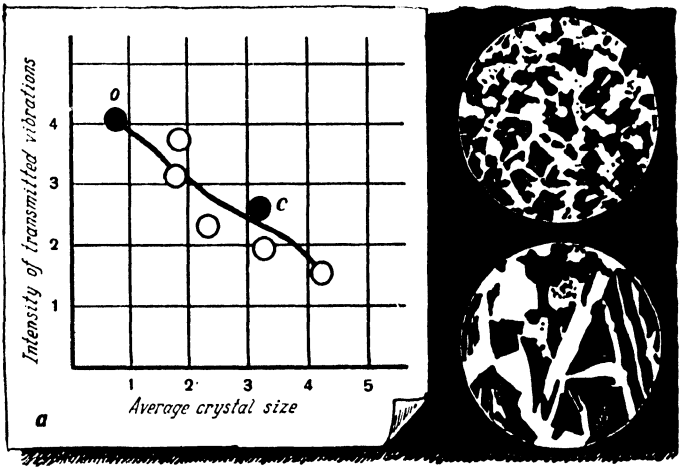


Fig. 45. Dependence of the intensity of transmitted pulses on the crystal size

very tiny droplets of water is not transparent to light. In this case there will be no bottom signal at all.

Figure 45 shows the relationship between the intensity of the supersonic signals after passing through the specimen and the grain size of the latter. At the right are shown micro-etchings of the specimens corresponding to points *b* and *c*. It can easily be seen that as the crystal grains grow in size the intensity of the supersonic pulses coming through the specimen decreases.

The impulse defectoscope can be used not only to check the quality of separate parts in the course of their manufacture, but also when they are already assembled into a machine or structure. For instance, it can be employed to check the quality of such important parts of an aeroplane as the longerons. Applying the projector to one end of the longeron the inspector watches carefully for the reflected signal. If there are no defects, only one echo will return

from the opposite end of the longeron, any additional reflections testifying to flaws in it. Soviet investigators have adapted this method of control to the detection of cracks occurring sometimes in rails. The supersonic defectoscope reveals defects so accurately that the rail is changed without further investigation. This method speeds up control operations by five to six times. It is used on the railways of the Soviet Union.

The detection of defects by means of echo-signals has an essential shortcoming.

We cannot distinguish echoes reflected from objects situated very close to us. Thus, if the reflecting surface, e.g., the wall of a large house, is about 300 feet away from us and we shout a short word, we may hear it repeated. But if we utter a long word, say, *audibility*, we shall hear the echo of only the end of the word—*ity*. This is due to the fact that the echo of the beginning of the word returns to us before we have finished pronouncing it and mixes with the sound of our voice, so that it cannot be distinguished. If the obstruction reflecting the sound is still closer, we shall not hear a distinct echo of the end of the word either.

Similar phenomena take place in the supersonic detection of defects: it is often difficult to notice flaws in a large specimen if they are situated near the surface. The time interval between the transmitted and reflected pulses is very small in this case and the reflected signal may return before the original signal is fully emitted. Hence, the indentations corresponding to the transmitted and the reflected signals will interfere on the screen of the oscillograph, forming one common indentation. To overcome this difficulty a device called a mechanical delay line is employed.

The mechanical delay line (Fig. 46) is a rod placed between the projector and the specimen under investigation. In this way the distance between the vibrator and the defect is increased, lengthening the time interval between the transmission of the signal and the return of the echo. With the aid of the mechanical delay line flaws can be discovered as close as 1/4 inch below the surface.

Mechanical delay lines have another very interesting application: they are one of the most important parts of the wonderful computing machines made recently, machines which perform various complicated mathematical calculations in a very short time.

When calculating we often have to "carry" certain numbers, i.e., to keep them in mind and subsequently add them when necessary. The calculating machine, in which the mathematical computations are performed as a result of a sequence of electric signals, has to be able to do something of a similar nature. If we wish the machine to "carry" a number, we have to delay the corresponding electric signal while other signals perform the necessary computations. This is done by transforming the electric signal into a supersonic signal by means of a quartz plate and directing it into a delay line which is usually an ordinary tube filled with mercury or a quartz rod. At the opposite end of the delay line the su-

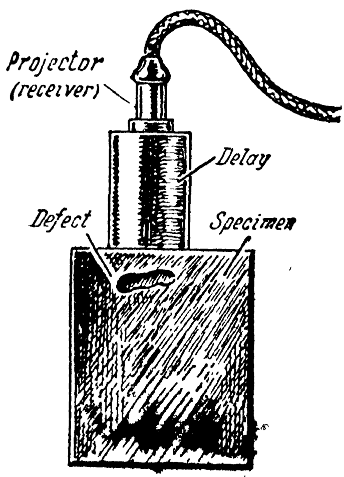


Fig 46. Mechanical delay line

personic signal is transformed back into an electric signal by means of a second quartz plate.

During the time it takes the supersonic signal to pass through the delay line, the computing machine completes various operations, to the result of which is added the supersonic signal transformed back into an electrical impulse. We can make the computing machine "carry" the result of any calculations for any desired time by changing the length of the path traversed by the sound: the longer the path of the sound, the longer the machine "remembers."

We must confess that in telling about the detection of defects by supersonics we have purposely skipped the difficulties encountered in this field, in the endeavour to bring out the opportunities offered by the method.

Now let us look briefly into these difficulties.

OVERCOMING OBSTACLES

A matter of great practical importance is checking the soundness of welds between steel sheets or parts of structures. Welds of this kind may always contain defects, but the latter are difficult to detect, because in practice the surface of the weld is always irregular, making it impossible to make a good contact between it and the supersonic projector.

One of the methods of supersonic detection of defects in welds is illustrated in Fig. 47. The projector and the receiver of the supersonic signals are situated on special prisms placed on either side of the weld, where the surface of the specimen is smooth.

Setting the projector on a prism makes the supersonic signal enter the specimen at an oblique angle to the sur-

face. When the supersonic signal reaches the opposite surface it is reflected and the receiver registers the bottom signal. If the defect is a horizontal one the receiver will register an additional echo. If it is vertical, the bottom signal will either be weakened or will disappear altogether.

Fig. *e*, Plate III, shows the cross-section of a weld with a slag inclusion detected by means of a supersonic defectoscope. As the defect was horizontal in this case, it was detected by the appearance of an echo-signal preceding the bottom signal.

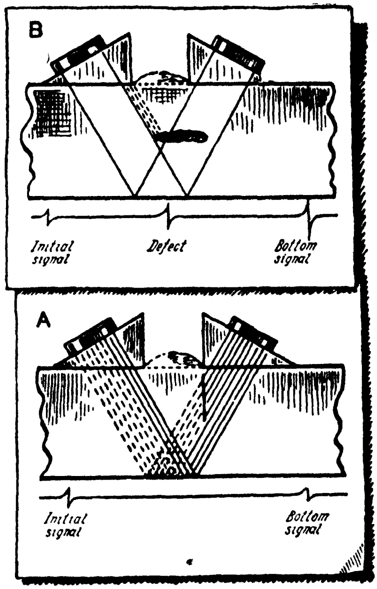


Fig. 47. Detection of defects in welds

Oblique incidence of the supersonic wave on a solid surface gives rise to complications owing to the fact that waves may be of two types: longitudinal and transverse. In longitudinal waves the separate particles of substance shift back and forth, vibrating in the same direction as the wave is propagated. In transverse waves the particles vibrate at right angles to the travel of the wave; so that if the wave is running horizontally the particles vibrate vertically, moving up and down.

Sonic waves are longitudinal in gases and liquids. But when a supersonic ray enters the part being inspected obliquely, a transverse wave arises in the metal besides the longitudinal one, its rate of propagation being almost

twice as small as that of the longitudinal wave. Naturally, the two kinds of waves give rise to two echo-signals. If we think of all the complications caused by repeated reflection of the waves and their interference, the difficulties connected with certain special cases of flaw detection will become clear to us, especially those concerning the investigation of welds.

Soviet scientists have overcome these difficulties. They placed an intermediate prism of special shape between the projector and the part under investigation (Fig. 48), causing the longitudinal wave to be totally reflected from the surface of the specimen. The reflected longitudinal wave is damped by a special device, and only the transverse wave penetrates into the body of the metal. This greatly simplifies the supersonic investigation of many important parts.

Obliquely incident rays have to be used not only in investigating welds.

The sensitivity of the supersonic defectoscope is high enough to permit determination of the depth of hardened layers of steel.

Many machine parts, as is known, are hardened to make them more durable. There is no need to harden the entire

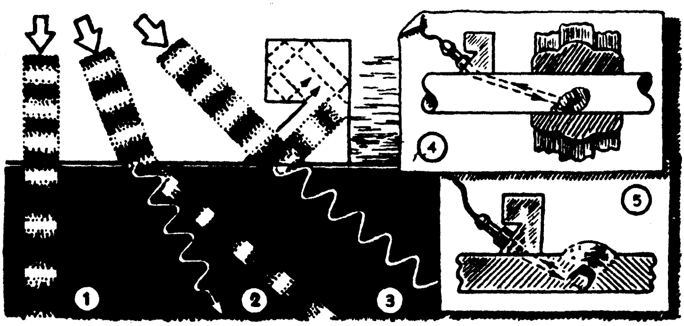


Fig. 48. Complete internal reflection of a longitudinal wave

part for this purpose, it being quite sufficient to harden only its outer layer.

In this case, just as in the investigation of welds, the supersonic ray is sent into the metal at an angle to its surface. The supersonic signal is reflected from the boundary between the hardened and unhardened layers. The quality of the hardened layer can be judged by the inten sity of the echo-signal.

SUPERSONIC DIAGNOSIS

Supersonic irradiation can be applied in medicine. The usual medium for medicinal radioscopy is X-rays. But the cerebrum is difficult to X-ray, because X-rays penetrate the cranium with difficulty.

Such is not the case with supersonic sound. The resistance of the cranium to supersonic vibrations is comparatively low, which suggested the use of supersonics instead of X-rays. Although only the first steps have been made in this direction, they are already worthy of mention.

The absorption of supersonic rays differs in various parts of the cerebrum. This makes it possible to study the structure of the cerebrum by through sounding. In particular, the structure of the ventricles of the brain can be studied in this way. The supersonic sound used in studying the cerebrum is of very low power and is quite harmless, just like ordinary audible sound.

X-ray and supersonic examinations of the cerebrum are compared in Fig. 49. The shaded regions show the outline of the ventricles of the brain as found by X-raying. Below are given the intensities of supersonic signals after passing through the cerebrum. The irradiation was carried out along a line dividing the cerebrum approximately in

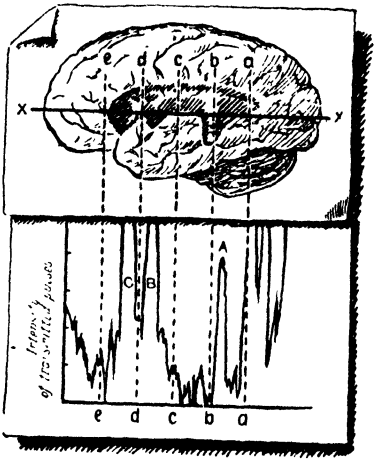


Fig. 49. Supersonic examination of the cerebrum

half. When the projector and receiver are moved along the line xx, the distance between them changes due to the rounded shape of the cerebrum. The relatively higher intensity of the signal received in the left-hand part of the figure is due to the fact that the path of the supersonic ray through the cerebral substance was rather short. As this path increases the intensity of the signal falls, up to point e. The two intensity peaks c and b correspond to the shaded regions to the right and left of point d in the upper figure. In these cases the path of the ray lies through the ventricles of the brain, and the absorption of vibrations is low. When the sound comes out of the ventricle region the intensity of the impulses transmitted through the cerebrum again decreases. This can be observed at points c and b.

The intensive signal A again corresponds to a shaded area on the upper diagram, i.e., to a ventricle of the brain. To the right of a the intensity of the signal coming through the cerebrum increases, but this is due to the shortening of the path traversed by the supersonic beam in passing through the brain substance rather than to decreased absorption of the sound in this substance. Supersonic investigation of the cerebrum gives rise to a number of difficulties. The supersonic signals are reflected by the skull bone and interfere with the emitted signals, altering their

intensity. To reduce complications a special chamber is used. The projector is completely isolated from the section of the chamber in which the supersonic receiver is located. If this arrangement is provided with a recording device it can be used to obtain a supersonic diagram representing the general outline of the ventricles of the brain.

In small doses supersonics can be utilized as a curative. The mechanism of the action of supersonic waves on the organism is not quite clear as yet, but it is probably of a dual nature. Absorbed by live tissues, supersonic sound turns into heat and causes intrinsic warming. On the other hand, the rapidly alternating vibrations act as a sort of massage. Supersonic waves are especially beneficial for all kinds of disorders of the peripheral nervous system, for inflammation of the sciatic nerve (sciatica), for neuralgia. Under the action of the supersonic vibrations the pain disappears, and in some cases complete recovéry follows.

Pathological changes in the organism can also be detected by means of supersonics.

SAVING HUMAN LIVES

An instrument very much like the reflecting defectoscope has been used lately with advantage for the detection of malignant tumours. Many difficulties were encountered in the solution of this problem. Owing to it's complex structure the human organism sent back a great number of echoes, and it was exceedingly difficult to get to understand them all.

But the difficulties did not daunt the investigators, and finally their persistency was rewarded. As a result of numerous experiments it was established that the echoes coming from normal tissue could be distinguished from

those coming from tissue attacked by a tumour. Moreover, when a tumour was detected the type of echo it sent back gave evidence of its nature. Echoes less dense than those reflected from the normal tissue were found to testify to the presence of benign tumours. Cancerous tumours, on the other hand, could be detected as zones of denser signals.

The merits of the new method became especially manifest when supersonics was employed to examine a patient in whom the physicians could not defect a tumour, though they suspected one to exist owing to an inflammatory process observed in his tissue. Supersonic examination revealed a very small tumour, but, judging by the nature of the supersonic signals, it was unquestionably malignant. A subsequent operation confirmed the diagnosis. The patient had a cancerous tumour extracted, only a little over 1/4 inch large. The insignificant size of the tumour had prevented it from being detected by usual methods.

Malignant tumours may appear in various organs, but observation has shown that they appear most often in definite parts of the organism, which should be the first to be examined. This is very much the same as with another serious disease – tuberculosis. Although tuberculosis may, generally speaking, affect any organ, only the chest is usually X-rayed, because pulmonary tuberculosis is the most common type. One of the most common forms of malignant tumours is cancer of the breast, and, naturally, one of the first instruments was designed to detect this form of the disease. The instrument is equipped with a miniature supersonic projector giving 15 million vibrations per second, the impulses being emitted one after the other at very short time intervals amounting to thousandths of a second. The returning supersonic echoes are transformed into light signals and observed on the screen of an electron ray tube.

A very complex radiotechnical device makes the ray in the electron ray tube move in such a way as to create on the screen an image of the cross-section of the tissue in the plane coinciding with that of the supersonic ray. On this image the lighter areas correspond to the more intensive echoes, and the dark areas to the less intensive ones.

The projector moves continuously back and forth in a chamber filled with distilled water and sealed with a rubber membrane. The chamber is applied to the part of the surface of the human organism which is to be investigated, and the supersonic pulses examine the part of the tissue next to the surface. The supersonic pulse is always perpendicular to the surface through which it is sent on its mission. The water in the chamber is an excellent conductor of supersonic signals, and the thin rubber membrane fits well against the human tissue, facilitating the passage of the signal. It is quite evident that an instrument which performs such complex operations cannot be of simple design. Besides the mechanical devices to secure continuous motion of the projector, the instrument has very complicated electronics, consisting of several dozen radio valves.

The depth to which the instrument allows us to penetrate into the human organism is limited by its following peculiarities. The first and most intensive echo arises at the boundary between the water in the chamber and the rubber membrane forming the wall of the chamber. Returning to the projector, this echo is reflected again, after which it travels in the same direction as the emitted signals. After a second reflection from the rubber membrane the signal gives rise to a second echo which disguises the feeble echoes coming from the tissues inside the human organism. The disguising action of the repeated echo limits the depth at which an image can be obtained. Tissues can be investigated by the above method to a depth of

about $1^1/_2$ in., which in many cases is quite sufficient. Combining the reciprocating motion of the projector with slow movement in a transverse direction, the physician can thoroughly investigate any part of a tissue in which he may suspect a tumour to have formed. It was by this method that the small cancerous tumour mentioned above was detected. Of course, it takes a specialist to make out the meaning of the sonograms, just as in the case of X-ray images of lungs affected by tuberculosis.

However, this instrument cannot be employed in all cases. For instance, in investigating the brain, part of the skull has to be removed to let the rubber chamber containing the projector come into direct contact with the cerebrum. If in investigating the tissue it were necessary to move the projector over its surface, a considerable part of the cranium would have to be removed. In this case it is more convenient to do as an observer standing on a hill and viewing the horizon. He just turns his head and examines the various parts of the horizon. At present the same principle is utilized in supersonic examinations of the human organism. In instruments of this type (so-called "sector scan echoscopes") a special mechanism keeps the supersonic projector continuously revolving, sending signals into the organism at various angles. Instruments of this kind are more complex in design, but they enable examination of relatively large areas of the organism without moving the projector.

Malignant tumours often appear in the stomach. For this reason a special instrument was designed for stomach examinations. In this instrument a miniature supersonic projector is fastened to the end of a soft rubber probe. Wires passing through the probe connect the projector with the rest of the apparatus and with the projector controls.

The projector is enclosed in a balloon of very thin rubber. The patient whose stomach is to be examined swallows the probe with the projector. The balloon is filled with water. The flexible rubber film fits snuggly against the walls of the stomach, ensuring passage of the supersonic signals when the stomach walls are being examined.

Not only malignant tumours can be detected by supersonic examination, but other pathological changes in tissues as well.

No doubt, in the near future instruments employing supersonics for examining patients will be considerably improved and will become valuable aids in the noble fight for human lives.

HOW SUPERSONICS HELPS TO INVESTIGATE THE STRUCTURE OF THE EARTH

The study of the structure of the Earth is a fascinating branch of science. But penetrating into the bowels of the Earth is far from easy: the depths we can reach by drilling are insignificant compared to the size of the Earth. The structure of the underlying layers can be ascertained by studying the phenomena that accompany earthquakes. B. B. Golitsyn, a gifted Russian scientist, said that an earthquake was like a "lamp, which flashes on for a short time, illuminating the interior of the Earth and thus enabling us to see what is going on there."

Indeed, a study of the waves arising in the Earth's crust during earthquakes helps us to become acquainted with the structure of the Earth. Sometimes scientists cause such waves artificially by making an explosion. The nature of the propagation of the waves in this case also makes it possible to delve into the depths of the Earth and prospect for useful minerals.

S. Y. Sokolov suggested the use of methods of supersonic flaw detection in model studies of the propagation of waves through the Earth's surface.

He found by calculation that if a supersonic wave is directed obliquely at the surface of a model of the globe, waves similar to those observed during earthquakes can be excited in the model. In order to make the nature of wave propagation in the model correspond to that observed in the Earth, the wavelength has to be decreased the same number of times as the model is smaller than the Earth. In practice the frequencies of the waves used for this purpose have to be from hundreds of thousands to tens of millions of vibrations per second.

If the relief of the model corresponds to that of the Earth's surface, the nature of wave propagation in the Earth's crust can be studied, and our conception of its structure verified. These remarkable ideas have already found practical application.

SUPERSONICS CONTROLS CHEMICAL CHANGE

So far we have been dealing with those applications of supersonic control whereby the properties of the substance investigated undergo no change. But we know that the velocity of sound depends on the properties of the substance, and, hence, if these properties change, the velocity of sound will change with them. This enables the use of supersonics in the study of various physico-chemical processes.

An especially important future practical application of supersonics is probably checking the solidification of concrete. It is very important for builders to know when this process is over. Both the through sounding method and the impulse echo method are used in the investigation of

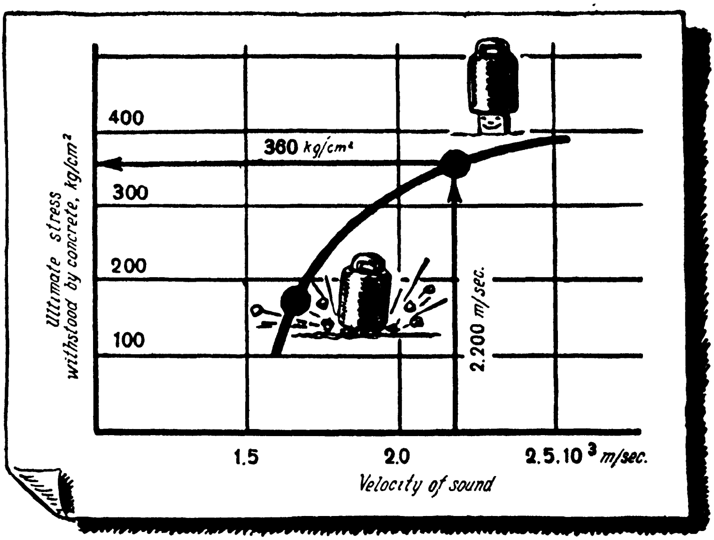


Fig. 50 Graph for determining the strength of concrete

hardening concrete. The instruments employed resemble those ordinarily used in the detection of defects. The supersonic impulses penetrate through the concrete to a depth of 100 feet, making it possible to investigate very large structures.

As the concrete hardens its strength increases and so does the velocity of propagation of supersonic vibrations through it. By measuring the velocity of the sound in the concrete and at the same time testing the strength of the latter, scientists have established the relationship between these two values. With a graph of this kind (Fig. 50) at his disposal, the builder can check the quality of the concrete right at the construction site. For this purpose a supersonic projector is applied to the concrete structure and a short signal is sent into the concrete. At the same time

the impulse is sent, a zigzag appears in the light ray on the screen of the instrument. When the reflected supersonic signal returns, a second zigzag appears at some distance from the first. The distance between the first and second zigzags corresponds to the time elapsed between the emission of the supersonic signal and the return of its echo. Knowing the dimensions of the object under investigation, the velocity of the sound can be determined, and hence the ultimate stress the concrete will withstand under compression can be found, this stress characterizing its mechanical properties.

Suppose the velocity of propagation of the sound was 2,200 m/sec. (about 7,220 ft. per sec.). If we raise a perpendicular to intersect the experimental curve shown in Fig. 50 and draw a line parallel to the horizontal axis from the point of intersection, we shall find that the ultimate stress the concrete can withstand upon compression equals 360 kg/cm^2 (about 5,120 lbs. per sq. in.).

Small sections of a concrete structure can be investigated also by sending narrow supersonic rays into them.

Supersonics has been used to inspect massive dams, as well as specimens from 8 inches to 50 feet long. Such investigations have made it possible to disclose even small cracks and to measure the depth of surface cracks. Supersonics has helped to determine the elastic properties of parts of structures inaccessible for direct visual inspection, to reveal sections of reduced strength.

Soviet physicists have designed a special instrument by means of which small changes in the velocity of sound can be measured with great accuracy. O. I. Babikov showed that this instrument could be used successfully to control the purity of water fed to steam boilers, turbines, etc. It can be used to keep track of the specific gravity of a

flowing liquid, to determine the concentration of alcohol solutions, to control the composition of various liquid mixtures.

HOW TO DETERMINE THE ELASTIC PROPERTIES OF SUBSTANCES

As we know, solid, liquid and gaseous bodies more or less resist attempts to change their volume. This property of bodies is called their bulk elasticity. Solid bodies, besides, resist changes in shape. They possess shape elasticity. In order to characterize the elastic properties of solid bodies quantitatively, special values are used, called elastic moduli.

One of the most common of these moduli is Young's modulus. Young's modulus is defined as the force which has to be applied to the ends of a rod of unit cross-section to stretch it to twice its original length.

Knowing Young's modulus we can tell, without actually performing the experiment, how much the shape of any part will change under a known stress, to what extent the part will resist the action of a force.

But a solid body cannot be stretched to twice its original length, and therefore Young's modulus has to be calculated from the results of observations of small changes in length caused by an applied force.

For instance, under a stress of seven tons (14,000 lbs.) a steel bar one yard long and one square inch in cross-section will stretch about 0.018 in., i.e., about one two-thousandth of its length. To double the length of the wire a force two thousand times as great would have to be applied—about 14,000 tons. Hence, Young's modulus for steel equals approximately 28,000,000 lbs. per sq. in.

It is sometimes difficult to determine Young's modulus by direct experiment, especially if the substance tested consists of separate tiny crystals. Therefore, in studying

the elastic properties of various substances indirect determinations are often made, employing the relationship between the elasticity of the substance and the velocity of sound in it.

Knowing the velocity of sound and the density of the substance we can calculate Young's modulus.

Several methods of determining the velocity of sound in solids have been developed. If a short supersonic impulse is sent into a test specimen in the shape of a rod, the impulse will run the length of the rod, be reflected by its opposite face and return to the projector that sent it. The emitted and reflected signals are made visible in the same way as in the defectoscope. If the sound does not damp greatly, a repeated supersonic echo will be observed on the screen of the oscillograph. Fig. *d*, Plate III, shows such repeated reflections of supersonic waves in a quartz plate at a frequency of one hundred million vibrations per second. By determining the distance between the indentations in the rays corresponding to the emitted and reflected signals, we can find the time it took the sound to reach the opposite face and come back.

If we now measure the length of the test specimen we can easily calculate the velocity of the sound, knowing which we can find the elasticity modulus of the substance in question.

There is another method, also often used for this purpose.

The test specimen in the shape of a long rod is clamped to a special stand, as shown in Fig. 51. A supersonic vibrator of variable frequency is applied to the lower end of the rod.

Under the influence of the vibrator the rod begins to oscillate. A special receiver is placed in the upper part and connected through an amplifier to an oscillograph, by means of which the forced vibrations can be observed.

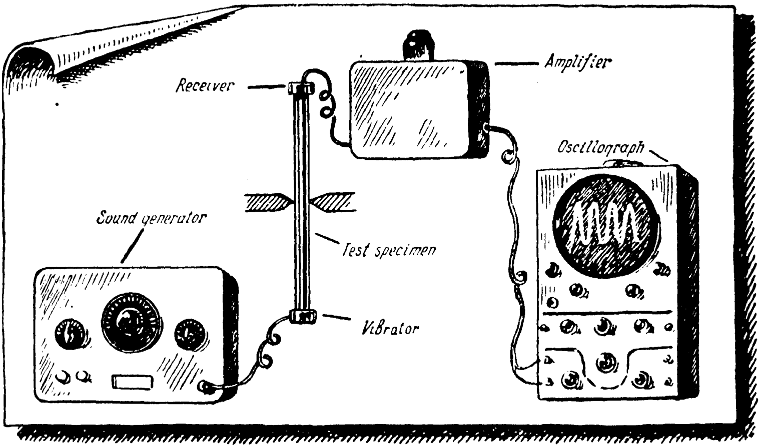


Fig. 51. Instrument for determining Young's modulus

If we gradually change the frequency of oscillation of the vibrator, we shall find that the intensity of vibration of the rod also changes. At a certain frequency, quite definite for each given specimen, its vibrations will reach a maximum. This frequency, as we know, will be the resonance frequency or the frequency of the rod's natural vibrations.

At the resonance frequency the amplitude of the wave on the screen of the oscillograph reaches a maximum.

Determining the frequency of the body's natural vibrations and knowing its shape and dimensions, we can calculate the velocity of sound in it and the elastic properties of the material.

If it is difficult or impossible to prepare a long rod of the substance to be investigated, a short one may be made and cemented to a long one of a different material. Determining the frequency of vibrations of the cemented specimen and knowing the elastic properties of the material of which the long rod is made, we can find the velocity of sound in

the short test rod. In this manner the velocity of sound and hence the elastic properties of various materials can be determined.

At present acoustic methods are especially widespread in the study of the elastic properties of various types of rubber and plastics.

This is because the elastic properties of these materials depend on the rate at which they are compressed or expanded.

When an automobile runs along a smooth highway, the rubber of the tyres is compressed more or less rapidly, depending on the speed of the vehicle. This may cause a change in the elastic properties of the tyre. In other words, the elasticity of the tyre depends on the speed of the automobile. A material may possess excellent properties at low speeds but be useless at high. For this reason it is of great practical importance to establish the relation between the elastic properties of a substance and the rate at which its shape is changed, i.e., the rate of compression or expansion of the specimen. Investigations of this kind are also carried out with the aid of supersonics. The relation just mentioned can be determined by measuring the velocity of sound at various rates of compression or expansion.

The design of supersonic instruments for determining the dimensions of bodies is also based on the determination of free vibration frequencies.

SUPERSONIC FLOW METER

It is often necessary to measure the rate of flow of a liquid. Sometimes the flow is inaccessible for direct observation. Sometimes it is necessary to measure the rate of flow without disturbing the nature of the flow and without introducing the measuring instruments into the liquid. Atom-

ic piles or reactors are now under design in which a molten metal—sodium—is employed to remove the heat from the reaction zone. In one such design the rate of flow of the metal is approximately 30 feet per second, which is close to the speed of an automobile car. The rate of flow of the metal must not decrease, otherwise an accident may occur. This is one of the examples of a liquid flow which is difficult of access for observation.

Another example is the movement of oil in a well far down below the Earth's surface. Finally we may mention measurement of the rate of flow of blood through the circulatory system of human beings or animals, particularly in the aorta. In this case the liquid flow is both difficult of access for observation and it is desirable not to obstruct it by introducing instruments of any kind. In our times such measurements can be carried out with the aid of supersonics. For this purpose use is made of the difference in the rate of upcurrent and downcurrent propagation of sound through a flowing liquid. The velocity of the sound when travelling downcurrent will be somewhat greater than upcurrent. Here we have the same phenomenon as in the upstream and downstream movement of a boat at constant speed along a river. If we measure the boat's speed from the shore we find that in the second case it is greater than in the first. This is due to the fact that when the boat is travelling downstream the velocity of the current adds to its speed, whereas when it is moving upstream the current of the river must be subtracted. If the true speed of the boat were known we could determine the velocity of the river current by observing this difference of speeds.

The velocity of sound in most liquids has been measured and therefore sound can be employed to determine flow rates.

If the liquid is flowing through a pipe we can measure the difference between the downcurrent and upcurrent velocities of the sound by fixing two piezoelectric plates to the outer walls of the pipe and making each of them alternately a supersonic projector and receiver. After this it is not difficult to calculate the rate of flow.

Sometimes the measuring instruments can be placed directly into the liquid flow, for instance, when studying sea currents. The apparatus designed for this purpose consists of a torpedo-shaped chamber inside which the measuring apparatuses are placed. A projector and receiver of supersonic signals are fastened to the chamber. The chamber is tied by means of a steel rope to a heavy drum which acts as an anchor. Inside the drum are storage batteries which can keep the apparatus in reliable operation for a week. A buoy floating on the surface of the water indicates the location of the measuring instrument. Within the chamber is a self-recording sound velocity meter, a clock that needs to be wound up only once a week, a compass and a photographic camera. The camera is operated every so often by means of a special relay and it records the readings of the compass, the clock and the apparatus for determining the velocity of the sound.

After development the film gives an idea of the velocities and directions of the sea currents in the course of a week. The above-described examples do not, of course, exhaust the possible applications of supersonic flow meters. No doubt these apparatuses will find wide application in various fields of human activity.

A THICKNESS GAUGE

The instrument shown in Fig. 52 was designed by V. S. Sokolov for measuring the thickness of metal, plastics, wood, etc., with very high accuracy.

A special projector is applied to the metal wall the thickness of which it is desired to measure. The frequency of the emitted wave is varied gradually. If the vibration frequency of the projector equals or is a multiple of the free vibration frequency of the wall, the vibrations of the latter will be especially intensive.

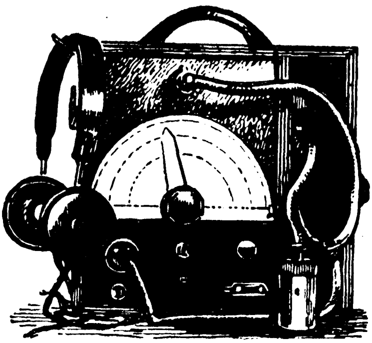


Fig. 52. Supersonic thickness gauge

The vibrations of the quartz plate are transformed by means of a special device into audible sound. This makes it possible to determine the intensity of the vibrations of the wall by ear as well. The instrument has a separate scale for each kind of material, graduated directly in terms of thickness. If the walls are parallel and smooth, the error of measurement is a fraction of a per cent. With irregular surfaces the error increases to 2-5 per cent.

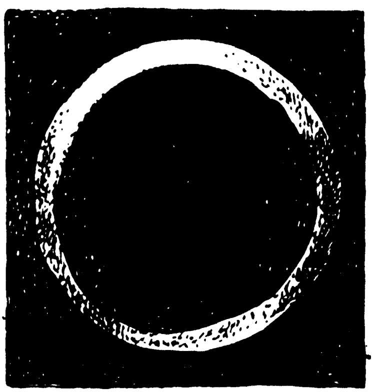


Fig. 53. Pipe wall inequalities detected by means of supersonics

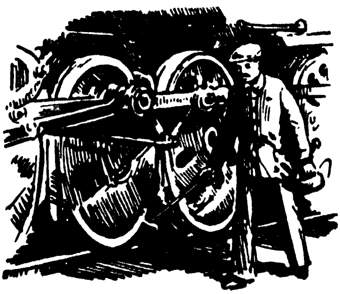
This instrument can be used even if the surface opposite that to which the projector is applied is bounded by water. Thus, the wall thickness of water pipes can be checked without interrupting the operation of the water main. It is quite possible also to

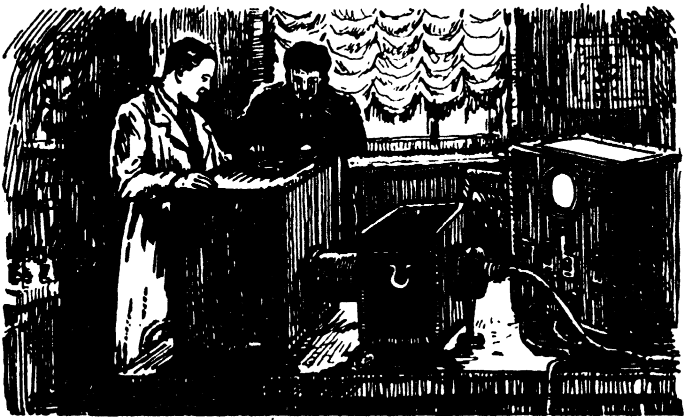
make an instrument to determine the thickness of the scale on the walls of a steam boiler without shutting it down.

The instrument makes it possible to measure wall inequalities in pipes (differences in the thickness of the pipe walls measured in cross-section). The result of such a measurement is shown in Fig. 53.

Supersonics permits determination of irregularities in glass, measurement of the elastic properties of various brands of glass.

By studying the changes in the velocity of sound in solids, the changes which take place in them with rising or falling temperature, etc., can be investigated.





Chapter 7

THE SUPERSONIC MICROSCOPE

SUPERSONIC OPTICS

To understand how the supersonic microscope works, we must recall the properties of the light rays used in ordinary optical microscopes.

If a double convex glass is placed in the path of the sun's rays the latter are refracted and converge at a point called the focus. Lenses make it possible to control the movements of light rays, to obtain images of objects magnified many times. Light rays are propagated through various substances at various rates. This difference in the rates of propagation is the cause of refraction.

The propagation of supersonic waves obeys the same laws as the propagation of light waves. We have seen more than once that supersonic waves can be reflected and re-

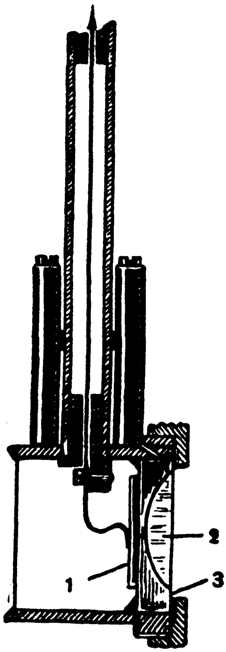


Fig. 54. Converging supersonic lens

fracted. Using special supersonic lenses and converging mirrors, we have learnt to control the movements of supersonic waves as well.

The velocity of sound in a liquid called carbon tetrachloride is much lower than in water. Therefore, if we fill a casing of aluminium foil shaped like a double convex lens with carbon tetrachloride, we get a supersonic lens. A lens of this kind will converge supersonic rays passing through water to a point. But in the air this lens will scatter or diverge the wave because the velocity of sound through carbon tetrachloride is considerably higher than through air.

Supersonic lenses are usually made of solid substances. It must be kept in mind that the velocity of sound in solids is much higher than in liquids or gases. Therefore, converging supersonic lenses are concave, and not convex. Scattering lenses, on the other hand, must be convex. Fig. 54 shows a supersonic lens of a plastic known as plexiglass. In order to improve the transmission of the vibrations, the quartz plate *1* is pressed firmly to the flat surface of the converging lens *3*. The cavity in front *2* is filled with water and sealed with a piece of thin metal foil. This protects the plexiglass from being attacked by the liquids in which the lens is submerged.

The supersonic vibrations converged by the lens can be intensified considerably by placing the quartz plate projector on a drum filled with air and faced with thin metal foil. The supersonic vibrations will then be reflected from

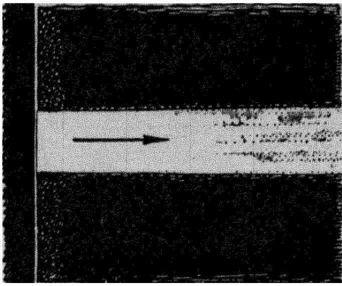


Fig. 55. Beam of parallel supersonic rays

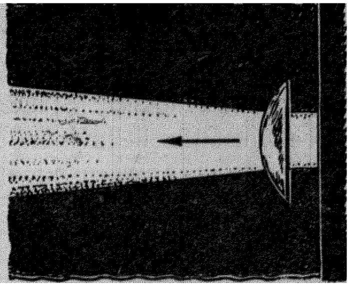


Fig. 56. Supersonic ray scattered by a lens

the surface bordering on the air and will be directed almost entirely towards the lens.

A convenient way of studying the refraction of supersonic rays is by making use of the optical non-uniformity they cause in the liquid through which they are propagated. If a light source of constant brightness is employed instead of intermittent illumination, an image of the supersonic wave will be obtained in the form of a bright ray. That is just how the supersonic ray caused in a liquid by a vibrating quartz plate and shown in Fig. 55 was photographed.

This ray can be diverged by placing a convex lens of plexiglass in its path (Fig. 56). On the other hand, a concave plexiglass lens will converge it to a point (Fig. 57).

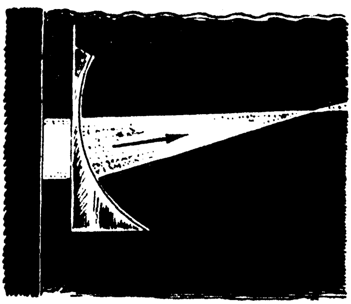


Fig. 57. A focussed ray

Converging comparatively weak supersonic vibrations propagated through oil to a point, the lens increases their intensity to such an extent

that a high fountain appears at the surface of the oil, drawn out into a narrow vertical stream.

As the wavelength of the sound decreases, the similarity between the behaviour of supersonic and light rays grows closer. Modern supersonic techniques enable us to obtain supersonic waves of wavelengths close to those of visible light.

With the aid of such sounds it has become possible to produce acoustic "images" of various objects, which can be magnified if desired. These properties are utilized in the supersonic microscope.

DESIGN OF THE SUPERSONIC MICROSCOPE

In Fig. 58 the object to be inspected—a piece of bent wire *2*—is in a vessel filled with a liquid. A beam of short supersonic waves, emitted by the quartz plate *1*, falls on the object. The reflected supersonic vibrations are focussed by the acoustic lens *3*, and an image of the object is produced on the quartz receiver plate *4*. In acoustic images the bright parts of the optical image correspond to the parts on which the most intensive supersonic vibrations fall, to the parts where the action of these vibrations is greater.

All that has to be done now is to change the latent acoustic image into a visible one. This can be done by utilizing the relationship between the electrical properties of a quartz plate and the pressure exerted on it. The latter gives rise to electrical charges on the receiver plate. The greater the intensity of the incident supersonic vibrations, the stronger their effect on it and, hence, the larger the electrical charge formed. The distribution of elec-

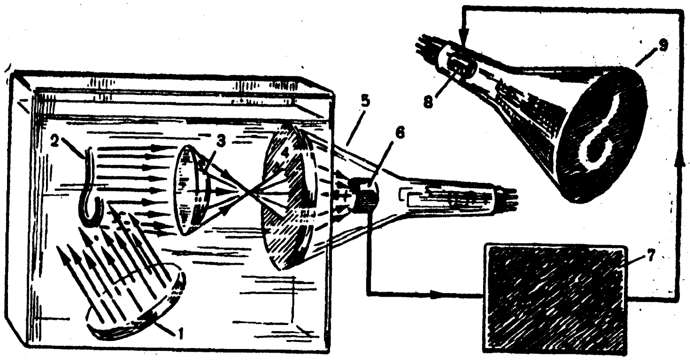


Fig. 58. Schematic diagram of supersonic microscope

trical charges over the plate will correspond to the image of the observed object that has to be made visible.

The receiver plate *4* forms the top of a cathode tube *5*. A narrow beam of cathode rays is incident on the inner surface of the receiver plate, from which it liberates so-called secondary electrons. These electrons are collected at the anode *6*. The number of electrons knocked out of any point of the receiver plate depends on the charge at that point. If the cathode ray moves over the surface of the plate, it will fall on areas of different charges and will therefore liberate various quantities of secondary electrons from each. The liberated electrons, moving inside the tube, give rise to an electric current of varying intensity, depending on the position of the cathode ray on the receiver plate and the distribution of charges over the latter, i.e., on the supersonic image produced on it.

The cathode ray is made to scan the entire surface of the plate line by line.

Starting at point *A* (Fig. 59) the cathode ray runs along the line and, coming to its end, instantaneously jumps

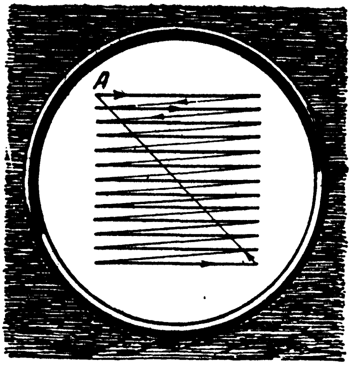


Fig. 59. Travel of electron ray in supersonic microscope

back to the starting point of the next line, just a little below the first, and moves along it at the same rate as before to the edge of the plate. Travelling in this way the ray covers from 20 to 30 lines each second. After the ray has gone over the whole square shown in the figure, it jumps back to point *A* and starts its journey all over again.

At the same time the intensity of the current (Fig. 58) passing through the tube *5* varies, depending on the image obtained on the receiver plate. A special instrument *7* amplifies these changes and they are delivered to the grid *8* of an electron tube *9*. The variations in current intensity cause corresponding changes in the intensity of the ray in the electron tube of an oscillograph. If the movement of the rays in the receiver tube and the tube of the oscillograph are synchronized, as in television, a visible image of the object observed through the supersonic microscope will result. The magnification of the supersonic microscope depends on the properties of the receiver tube *5* and the tube *9* of the cathode oscillograph.

Calculations show that magnifications of several tens of thousands of times are possible with the supersonic microscope.

The object observed through the supersonic microscope may be "illuminated" either by continuous supersonic waves or by intermittent supersonic pulses.

The design of the supersonic microscope may be altered, retaining its working principle. In one of the designs the

supersonic image is produced on the outer surface of a piezoelectric plate *1* (Fig. 60), the inner surface of which is illuminated evenly with ultraviolet rays *3*. Under the action of the ultraviolet rays electrons are liberated from the inner surface of the plate, which forms the top of a vacuum tube *2*. These electrons are accelerated by an electric field, pass through special magnetic and electrical lenses and strike a fluorescent screen *5*, imprinting on it a visible image of their source, the piezoelectric plate *1*. The liberation of electrons by the ultraviolet rays depends on the magnitude of the charges formed on the plate under the action of the incident supersonic vibrations. The intensity distribution of the latter depends, in its turn, on the acoustic image produced on the receiver plate. Hence, the object observed will be seen magnified on the screen *5*.

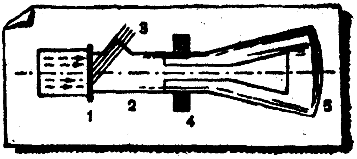


Fig. 60. Diagram of supersonic microscope with magnetic lens

A NEW DESIGN

In 1952 the design of the supersonic microscope was greatly simplified.

As before, the object to be observed, *2*, is placed in a liquid *4* and "illuminated" with a homogeneous supersonic beam emitted by the quartz plate *1* (Fig. 61). After reflection by the object the supersonic rays fall on the mirror *3* which throws the image of the object on to the surface of the liquid. When the supersonic rays reach the surface of the liquid, they cause characteristic ripples on it. If supersonic rays of small wavelength are used, the ripples are very uniform. Illuminating the surface with an obliquely

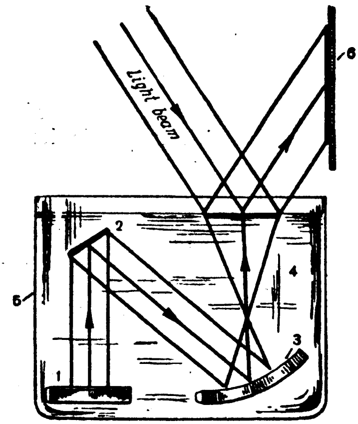


Fig. 61. Diagram of new design of supersonic microscope

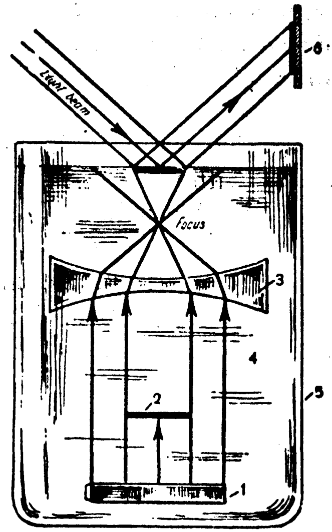


Fig. 62. Diagram of new design of supersonic microscope with lens

incident light beam, we can throw an image of the surface on to the screen *6*, where all the irregularities caused by the supersonic image will be visible. In the new design of supersonic microscope the image of the object observed can be produced also by means of a lens, as shown in Fig. 62. Here, as above, the image of the object is distinctly delineated against the background of the ripples.

The quality of optical instruments depends on their "resolving power," defined as the least distance between two points which can be distinguished with the aid of the instrument. If the points are closer together than the resolving power of the instrument, they will appear merged into one.

The shorter the wavelength, the higher the possible resolving power. Supersonic sound with a frequency of a thousand million vibrations per second has a wavelength

approaching that of visible light. But the resolving power of the supersonic microscope depends greatly on the properties of the quartz plate emitting the supersonic ray as well. As to the wavelengths, those produced for supersonic waves at present are not the limit, so there are grounds to expect higher resolving power in the supersonic than in the optical microscope. Fig. 63 shows the supersonic microscope.

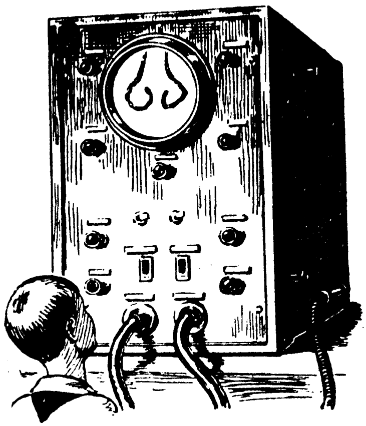


Fig. 63. Front view of supersonic microscope

PRACTICAL APPLICATION OF THE SUPERSONIC MICROSCOPE

The supersonic microscope enables us to see what cannot be seen with the naked eye or with an optical microscope.

Fig. 64 is a photograph, obtained with the aid of a supersonic microscope, of a wire submerged in an opaque liquid. In this case the magnification of the supersonic microscope was 10×.

When examining images under the supersonic microscope, it should be kept in mind that the light and dark areas of these images do not coincide with the light and dark areas of images in the optical microscope. Small cavities in a solid, which we should expect to be seen as lighter areas, actually appear darker due to the reflection or absorption of the sound. Fig. 65 is a supersonic image of a glass rod (left) and a glass tube (right). Glass is trans-

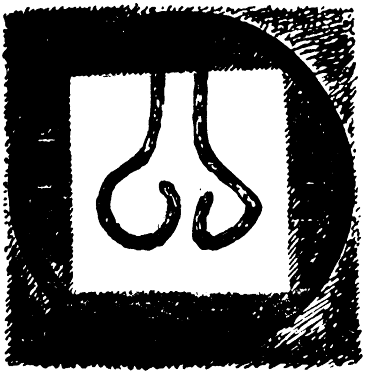


Fig. 64. Pieces of wire in an opaque liquid

parent to supersonic vibrations, and hence the light areas on the image of the rod. Supersonic sound cannot pass through the tube, which is filled with air, and hence the uniform shade in its image.

The supersonic microscope makes it possible to detect flaws in metallic coatings on a quartz plate. In Fig. 66 light spots resembling stars can clearly be seen; these are areas where the silver coating did not adhere well to the surface of the plate and exfoliated. It is very difficult to detect such defects by other methods.

Supersonic sound is very sensitive to changes in the density of substance. Therefore streams of hot liquid (Plate IV, *c*) will be registered accurately by the supersonic microscope. Engineers and scientists can observe the heat

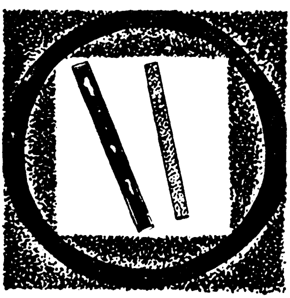


Fig. 65. Image of glass rod and glass tube produced in supersonic microscope

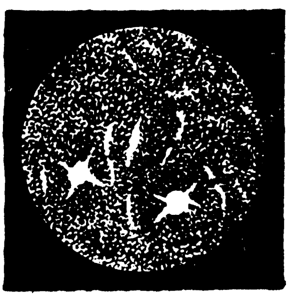


Fig. 66. Exfoliated spots in a silver coating revealed by the supersonic microscope

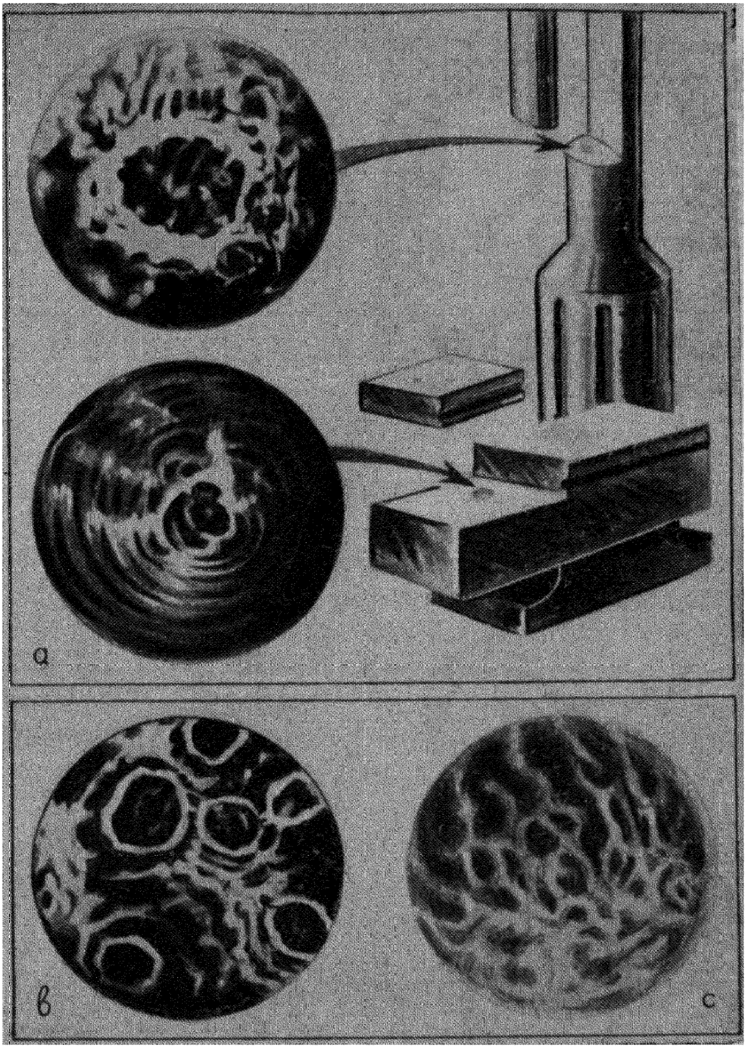


Plate IV

a—defects in a metal article revealed by the supersonic microscope;
b—droplets of water in kerosene as seen through a supersonic microscope;
c—thermal currents observed with the aid of the supersonic microscope

flows arising in liquids. If the liquid is transparent, the optical method is used. But for opaque substances the supersonic microscope has no rival. This instrument makes it possible to determine the design required for various types of heaters and to impart to them the shape which guarantees quickest heat convection and uniform heat distribution throughout the liquid.

The transparency of water is approximately the same as that of kerosene, making it difficult to obtain images of water drops in kerosene by optical methods. Now take a look at *b*, Plate IV. The supersonic microscope has detected droplets of water in kerosene, each droplet being surrounded by a distinct white fringe.

The supersonic microscope is especially important as an instrument for finding defects in metal. Its sharp eye will not miss a flaw even if it is far below the surface of the metal. Fig. *a*, Plate IV, shows supersonic images of defects detected in metal parts at depths of 24 and 4 1/2 inches.

A supersonic image observed on the surface of a liquid is seen in relief and seems stereoscopic.

The remarkable properties of the supersonic microscope mentioned in the foregoing and primarily the possibility of using it to examine magnified images of objects concealed from the human eye under a thick layer of opaque substance, are a security of the wide application of this instrument in various branches of science and engineering.

* * *

This book has not exhausted all the applications of supersonics. Little has been said of the use of supersonics in research work. For instance, the processes taking place in gases as a result of collisions between the molecules can be investigated by studying the propagation of supersonic sound through the gas. Physicists know that such colli-

sions result in the molecules passing into a peculiar "excited" state. Supersonics makes it possible to investigate the details of the process, to determine the lifetime of the excited molecule, the influence of various adulterants introduced into the gas, and to study a great many other interesting problems.

Supersonics helps to trace the course of chemical reactions, to determine the composition of various mixtures.

The interaction between the molecules of the solute and the solvent in a solution can be studied by investigating the propagation of sound through the solution. Supersonics makes it possible to detect and study processes taking place in solids upon heating.

The science of inaudible sounds is developing so rapidly that almost every issue of various physics periodicals brings word of new achievements in the study of the properties of supersonic sounds and of their applications for the welfare of mankind.

The study of inaudible sounds is not only interesting from a theoretical point of view, not only deepens our knowledge of nature, but is of great practical importance as well. Supersonics is finding wider and wider application in various branches of human activity. No longer do only physicists use it in their practical work, but also chemists, biologists, engineers, physicians.

The finest dispersion of substances, improvement of the quality of metals, the use of supersonics in model studies of the acoustic properties of various structures, the detection of very small defects, concealed deep down in the metal, control over the course of chemical changes, and, finally, the production with the aid of supersonic waves of magnified images of objects even when enveloped in opaque

shells—such is the by no means complete list of the achievements scored by the science of inaudible sounds.

In the numerous laboratories of various institutions Soviet scientists keep inventing more and more new methods of the practical application of supersonics for the good of their country.

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Б. КУДРЯВЦЕВ

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